IMPACTS OF DISTRIBUTED GENERATION ON AIR QUALITY: A ROADMAP

CONSULTANT REPORT

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Preface

The California Energy Commission's Public Interest Energy Research (PIER) Program supports public interest energy research and development that will help improve the quality of life in California by bringing environmentally safe, affordable, and reliable energy services and products to the marketplace.

The PIER Program conducts public interest research, development, and demonstration (RD&D) projects to benefit California.

The PIER Program strives to conduct the most promising public interest energy research by partnering with RD&D entities, including individuals, businesses, utilities, and public or private research institutions.

PIER funding efforts focus on the following RD&D program areas:

- Buildings End-Use Energy Efficiency
- Energy Innovations Small Grants
- Energy-Related Environmental Research
- Energy Systems Integration
- Environmentally Preferred Advanced Generation
- Industrial/Agricultural/Water End-Use Energy Efficiency
- Renewable Energy Technologies
- Transportation

Impacts of Distributed Generation on Air Quality: A Roadmap is the final report for the Center for Clean Air Studies Initiative project (contract number 500-02-004, WA MR-026) conducted by the University of California at Riverside. The information from this project contributes to PIER's Energy-Related Environmental Research Program.

For more information about the PIER Program, please visit the Energy Commission's website at www.energy.ca.gov/pier or contact the Energy Commission at 916-654-5164.

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Abstract

The Environmental Area of the California Energy Commission's Public Interest Energy Research (PIER) Program sponsored a series of meetings with representatives of state agencies and universities to determine the status of distributed generation resources in California. Distributed generation resources are grid-connected or stand-alone electrical generation or storage systems, connected to the distribution level of the transmission and distribution grid, and located at or very near the end user. Participants discussed and identified the kinds of research activities that would be necessary to support the continued improvement of California's air quality as distributed generation use increases. Based on these discussions and further research, a research roadmap was developed to prioritize this research and identify collaborative opportunities. The participants concluded that there is a need to: (1) assess the air emission characteristics, efficiency, and waste heat use of distributed generation equipment, along with impacts from public exposure to the emissions, (2) develop better monitoring and modeling techniques to assess the ground-level concentrations of air contaminants, (3) assess the life-cycle effects of distributed generation technologies, (4) evaluate emission control technologies and develop improved controls as needed, and (5) conduct comprehensive analyses of distributed generation penetration and use to begin to predict these systems' effects on public health, the environment, and the electricity system.

Keywords: Distributed generation, DG, combined heat and power, dispersion modeling, life-cycle assessment, emissions, emissions reductions

Executive Summary

More than 2,000 megawatts of electrical generation capacity in California is classified as distributed generation equipment. Distributed generation resources are grid-connected or stand-alone electrical generation or storage systems, connected to the distribution level of the transmission and distribution grid, and located at or very near the end user. Distributed generation technologies can offer benefits such as improved electricity reliability and power quality, competition against central plant generation, and the ability to generate electricity in remote locations. Some distributed generation technologies can also produce fewer emissions than central station power plants. For these reasons, the California Public Utilities Commission and the California Energy Commission (Energy Commission) are encouraging the use of distributed generation, and the Energy Commission's *Distributed Generation Strategic Plan* outlines activities that would increase the implementation and use of distributed generation in the state.

However, at this time, most combustion distributed generation technologies that do not use significant amounts of waste heat are less efficient than state-of-the-art, combined-cycle, natural gas power plants (the current generation technology standard for baseload power plants). Furthermore the emission controls for many combustion distributed generation technologies are not fully implemented or maintained. The desire for a thoughtful deployment of these technologies was stressed in California Senate Bill 1298,[1] which states: "It is in the public interest to encourage the deployment of distributed generation technology in a way that has a positive effect on air quality." Research to better understand and improve distributed generation technologies will help Californians benefit from these technologies by preventing a potential increase in local and regional air pollution**.**

Combustion distributed generation emissions are a source of criteria compounds, such as sulfur oxides, nitrogen oxides, and particulate matter; and air toxics, such as formaldehyde, that contribute to urban, regional, and global pollution. One study predicts near-term increases in sulfur oxides, carbon monoxide, carbon dioxide, volatile organic compounds, and particulate matter from a greater use of distributed generation units.[2] Other research by the South Coast Air Quality Management District has shown that in-use combustion distributed generation emissions are commonly in extreme exceedance of their permitted levels.[3] Analyses such as these point to a need for improved understanding of the actual emissions from existing and emerging combustion distributed generation technologies.

The Public Interest Energy Research Environmental Area has identified five fields of research that will support the continued improvement of California's air quality as distributed generation use grows. First, there is a need to determine the air emission characteristics, efficiency, and waste heat

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[1] SB 1298 (Bowen and Peace, Chapter 741, Statutes of 2000, Section 1(e)).

[2] Iannucci, Joseph et al. *Air Pollution Emission Impacts Associated with Economic Market Potential of Distributed Generation in California.* Distributed Utility Associates. June 2000.

[3] Kay, Martin. 2006. Emissions from In-use IC Engine DG & Lessons Learned. SCAQMD. October 3, 2006. www.energy.ca.gov/pier/conferences+seminars/2006-10-3+4_electricity_air-quality_conference/presentations/session_02/12Kay.ppt.

use of emerging DG systems in the state, as well as their accompanying public exposure impact. Second, researchers must develop better monitoring and modeling techniques to assess ground-level concentrations of air contaminants associated with distributed generation installations. Third, research must assess the life-cycle impacts of distributed generation technologies. Fourth, research efforts must evaluate emission control technologies and develop improved controls as needed, to minimize air emissions from distributed generation power plants. Some of these emissions can be reduced with control technologies, and the efficiencies of these units can be improved when they are integrated with combined heat and power applications. And fifth, researchers must conduct comprehensive analyses of distributed generation penetration and use to begin to predict the effect that these systems will have on public health, the environment, and the electricity system.

The successful completion of the activities noted in the Goals section will help the state maintain healthy air as more distributed generation power facilities are installed in California. The activities recommended in the roadmap address a range of emissions: criteria compounds that affect human health and the environment, non-criteria compounds (such as methane) that influence global warming and visibility, and other derived secondary compounds.

The products from this research can be used by air quality management districts to improve emission inventories and help develop appropriate regulations for combustion distributed generation as the use of these technologies expands. This research can also help public health experts asses public health impacts from combustion distributed generation. It is likely that results would also contribute to the development of more effective control technologies for distributed generation equipment. All of the information developed should help end users, manufacturers, and regulatory agencies make well-informed decisions regarding the implementation of these technologies in California.

In the short term (1–3 years), this roadmap finds that the following objectives are all candidates for high priority funding:

Objective	**Projected Cost ($000)**
5.1.1.A Assess emissions of future distributed generation systems	500
5.1.1.B Support the development and standardization of criteria pollutant test protocols	600*
5.1.1.C Determine emissions profiles of existing and emerging distributed generation systems and degradation of units	500*
5.1.2.A Evaluate and improve dispersion modeling techniques	450*
5.1.2.B Conduct selected dispersion modeling field studies	400*
5.1.2.C Conduct uncertainty analysis of dispersion modeling results	200*
5.1.3.A Conduct life-cycle assessment of distributed generation technologies	750*
5.1.4.A Evaluate the performance of distributed generation emissions reduction technologies, fuels, and efficiency improvement	700*
5.1.4.B Initiate development of necessary controls, heat recovery technologies, and other process improvements	500*
5.1.5.A Project the future use of specific distributed generation technologies	450

Note: An asterisk (*) indicates a high probability that the work will be leveraged with other ongoing efforts. The figure given is the California Energy Commission's projected expenditure to complete the short-term work.

The Public Interest Energy Research Environmental Area distributed generation roadmap also identifies mid-term (3–10 year) and long-term (10–20 year) goals, some of which build on the short-term work listed above.

Roadmap Organization

This roadmap is intended to communicate to a broad audience with varying levels of knowledge about the issue. The sections build upon each other to provide a framework and justification for the proposed research and development—both for stakeholders well-versed in distributed generation issues, as well as for those new to the issues.

Section 1 states the issue to be addressed. *Section 2: Public Interest Vision* provides an overview of research needs in this area and how PIER plans to address those needs. *Section 3: Background* establishes the context of PIER's distributed generation work. *Section 4: Current Research and Research Needs* surveys current projects in this area and identifies specific research needs that are not already being addressed by those projects. *Section 5: Goals* outlines proposed PIER-EA activities that will meet those needs. *Section 6: Leveraging R&D Investments* identifies methods and opportunities to help ensure that the investment of research funds will achieve the greatest public benefits. *Section 7: Areas Not Addressed by this Roadmap* identifies areas related to distributed generation research that the proposed activities do not address. *Appendix A: Current Status of Programs* offers an overview of work being done to address distributed generation issues.

1.0 Issue Statement

There is a need for improved methods, tools, and data to estimate impacts of distributed generation (DG) technologies (and other emerging technologies) and fuels on air quality.

2.0 Public Interest Vision

Plans to ensure that California has an affordable, reliable, and resilient electricity supply include an expanded role for a wide variety of DG technologies.[4] The joint Energy Action Plan released by the California Public Utilities Commission (CPUC), the California Energy Commission (Energy Commission), and the California Power Authority (CPA) promotes and supports the development and implementation of customer- and utility-owned DG in California. Moreover, it emphasizes a preference that new electricity generation facilities be either renewable or DG technologies (CPUC, CEC, and CPA 2003).

The Energy Commission articulated its vision of the future of distributed generation in the State in its *Distributed Generation Strategic Plan,* which identified issues and opportunities that affect the likelihood of that vision being realized and addressed government's role in that process (CEC 2002). A stated goal of that plan is to:

> Enhance the emissions and efficiency profiles of DG technologies, monitoring, and modeling techniques, and cost-effective control technologies such that the resulting environmental impacts, public exposure, and permitting support wide-scale deployment.

Accordingly, one mission of the Public Interest Energy Research Environmental Area (PIER-EA) is to help implement this vision by helping Californians reap the benefits of DG technologies while ensuring that there is no decline in air quality from their emissions.

More than 2,000 megawatts (MW) of electrical generation capacity in California is classified as DG equipment (CEC 2002). Distributed generation technologies can offer benefits such as improved electricity reliability and power quality, competition against central plant generation, and the ability to generate electricity in remote locations. For these reasons, the CPUC and the Energy Commission are encouraging the use of DG, and the Energy Commission's strategic plan outlines activities that would increase the implementation and use of DG in the state.

However, most combustion DG technologies, if used without heat recovery, are less efficient than state-of-the-art, combined-cycle, natural gas power plants (the current generation technology standard for baseload power plants), and their emissions can be higher and effect people's health because the generation source is closer to the population. The desire for a thoughtful deployment of these technologies was stressed in California Senate Bill 1298, which states: "It is in the public interest to encourage the deployment of distributed generation

[4] For an overview of distributed energy technologies, see the Background section (Section 3).

technology in a way that has a positive effect on air quality."[5] Without research to improve DG technologies, and science-based standards to regulate their emissions, a significant addition of combustion DG equipment in California has the potential to increase local and regional air pollution.

To support continued improvement in California's air quality as DG use grows, research and development is needed in five areas:

- There is a need to better assess the air emission characteristics, efficiency, and waste heat use of installed and emerging DG systems in the state, as well as their accompanying public exposure impact.
- Researchers must develop better monitoring and modeling techniques to assess ground-level concentrations of air contaminants associated with DG installations, because many of these technologies emit pollutants at ground level in areas with high population density.
- Research must assess the life-cycle impacts of distributed generation technologies.
- Research efforts must evaluate emission control technologies and develop improved controls as needed, to minimize air emissions from DG power plants. Some of these emissions can be reduced with control technologies, and the efficiencies of these units can be improved when they are integrated with combined heat and power applications.
- Researchers must conduct comprehensive analyses of DG penetration and use to begin to predict the effect that these systems will have on public health, the environment, and the electricity system.

Combustion DG emissions are a source of criteria compounds, such as sulfur oxides (SO_X) and particulate matter (PM), which can affect respiratory and cardiac functions; nitrogen oxides (NO_X), which are smog precursors and can damage lungs and affect fetal development; and carbon monoxide (CO), which affects blood's ability to absorb oxygen. Combustion DG units also emit carbon dioxide (CO_2), which contributes to global warming; volatile organic compounds (VOC), which contribute to the formation of smog and/or may be toxic; and air toxics, which include a wide range of chemicals (such as formaldehyde and dioxins) that can increase cancer risks and birth defects and cause immune system and neurological damage. One study predicts near-term increases in SO_X, PM, NO_X CO, CO_2, and VOC from a greater use of DG units (Iannucci 2000). Analyses such as these point to a need for improved understanding of the actual emissions from existing and emerging combustion DG technologies.

The successful completion of the activities noted in the Goals section (Section 5) will help ensure that California will maintain healthy air as more DG power facilities are installed. The projects outlined in this roadmap address a range of emissions, from criteria and toxic compounds that affect human health and the environment to non-criteria compounds (such as methane) that influence global climate change, visibility, ozone, and other derived secondary compounds.

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[5] SB 1298, Bowen and Peace, Chapter 741, Statutes of 2000, Section 1(e).

The products from this research can be used by air quality management districts to improve emission inventories and help develop additional regulations for combustion DG. This research can also help public health experts asses public health impacts from such sources. It is likely that results would also contribute to the development of more effective control technologies for DG equipment. All of the information developed should help end users, manufacturers, and regulatory agencies make well-informed decisions regarding the implementation of these technologies in California.

3.0 Background

3.1. Definition and Market and Technology Readiness

Distributed generation technologies are grid-connected or stand-alone electrical generation or storage systems, connected to the distribution level of the transmission and distribution grid, and located at or very near the end user. Such systems are typically small (that is, less than 50 MW) and modular. Distributed generation equipment can be used as a primary source of electricity, to help ensure improved power quality and reliability, or for peak shaving (i.e., as an electricity source during peak demand periods, when electricity from the power grid is less available and more expensive). These units may be located at a customer's premises on either the utility or customer side of the meter or located at other points in the distribution system, such as a utility distribution substation. Distributed energy technologies include microturbines, small gas turbines, fuel cells, internal combustion engines, diesel engines, photovoltaics, Stirling engines, and wind turbines. Configurations of distributed energy technologies include the installation of a single system or the aggregation of multiple units, and may involve the use of combined heat and power (CHP). Many combustion distributed energy technologies use natural gas; however, backup generators, or BUGs (which are generally not connected in parallel with the power grid or used as primary electricity generators) mostly use diesel fuel, because it is relatively inexpensive, the fuel can be stored onsite, and the fuel has a high energy content per unit volume, which minimizes necessary storage space.[6] Most combustion DG equipment can be adapted or designed to use more than one fuel.

Distributed generation technologies are often proposed as one solution to California's electricity needs, mainly because of their short installation time and ability to supply discrete loads competitively and with improved reliability. However, as a group, DG technologies are at widely differing states of development. Diesel engines, for example, are readily available today in a wide range of sizes, although emissions control technologies for diesel units are not fully mature, so some emissions from these systems are typically quite high, making them unfeasible as a primary power source. At the other end of the spectrum, advanced fuel cells are expected

[6] This DG roadmap mentions BUGs because they are currently the most prevalent source of onsite power generation in California and because some of the techniques that have been used to analyze their use and performance can be applied to DG units.

to be highly efficient, low-polluting electricity generators, but they may not be commercially available at competitive prices for years. Because many DG technologies are new, their current and future market penetration is unknown, which increases the difficulty of determining their environmental impacts.

Many renewable distributed generation units are commercially available, and the efficiency and cost of these units varies drastically. Although commercial combustion DG technologies are less clean and/or less economical than combined-cycle natural gas power plants, emissions, efficiency, and cost-effectiveness improve when this equipment is installed as part of a CHP application. For example, estimated efficiency for 16–60 kilowatt (kW) microturbines is about 28% (U.S. DOE 2002) or lower (CEC 2002); however, the combined electrical and thermal efficiency of a microturbine may reach as high as 85% (CEC 2002). Although such high efficiency is possible, its attainment in the real world is not guaranteed, because all of the expected waste heat must be used to reach that potential.

To facilitate the introduction of DG technologies, the federal government and many states have been developing DG interconnection regulations. In 2005, the Federal Energy Regulatory Commission (FERC) issued standard procedures for interconnection of generators less than 20 MW.[7] The California Public Utilities Commission adopted interconnection standards for investor-owned utilities (Rule 21) in 2000, to help encourage DG penetration by streamlining the process. The Energy Commission published a guidebook to help steer users through the interconnection process (CEC 2003a) and has since published supplementary materials.[8] A Rule 21 Interconnection Working Group continues to refine interconnection language, standardize application forms, develop certification and interconnection databases, and evaluate the success of these standards in practice.[9] In 2003, the National Association of Regulatory Utility Commissioners (NARUC) published a document for voluntary adoption or adaptation by states that wish to harmonize state approaches to DG interconnection (NARUC 2003). The Institute of Electrical and Electronics Engineers (IEEE) published the IEEE 1547 Standard for Interconnecting Distributed Resources with Electric Power Systems, which covers all distributed generation technologies and considers much larger systems and grid impacts. The standard was approved by the IEEE Standards Board and as an American National Standard in 2003.[10] Underwriters Laboratories (UL) 1741, the interconnection test standard, expanded its scope to match 1547 (Haynes and Whitaker 2007).

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[7] See Federal Energy Regulatory Commission. Generator Interconnection. www.ferc.gov/industries/electric/indus-act/gi/small-gen.asp.

[8] California Energy Commission. California Distributed Energy Resource Guide. www.energy.ca.gov/distgen/interconnection/interconnection.html.

[9] California Energy Commission. Rule 21 Working Group. www.rule21.ca.gov/.

[10] The published standard is available from the IEEE Std 1547-2003 website, at (http://grouper.ieee.org/groups/scc21/1547/1547_index.html).

3.2. Setting Emissions Performance Standards and Permitting Conditions

Distributed generation units that generate less than 50 MW are excluded from the Energy Commission's power plant siting jurisdiction, and the California Public Utilities Commission is not required to issue permits for these units unless an investor-owned utility owns the facility. Therefore, permitting and approval for most DG units has fallen to the cities, counties, air districts, and California Air Resources Board (ARB)—or has been altogether missing. Under its Statewide Portable Equipment Registration Program, ARB does issue permits for portable engines and portable equipment, which it defines as …"an internal combustion engine which is designed and capable of being carried or moved from one location to another and does not remain at a single location for more than 12 consecutive months." This definition includes engines used as electricity generators, but it is a small subset of commercially available DG technologies. As this roadmap is being written, ARB is revising this program. For current information, see the program's website, at www.arb.ca.gov/portable/perp/perp.htm.

Until 2002 California had not developed uniform emission standards for DG permitting, because the units were not very prevalent in the state. However, the increasing need of some users to better control the costs, reliability, and quality of their electricity suggests that demand for DG will grow as the economics and performance of these technologies continue to improve and interconnection and regulatory barriers are overcome. Public subsidies of these technologies also may increase. A study from the Office of Ratepayer Advocates at the California Public Utilities Commission examined the cost-effectiveness of financial incentives for some distributed generation technologies and found that programs involving grid-independent photovoltaics, natural gas- or propane-fired microturbines, and fuel cells "…may be substantially more cost-effective for removing load from the grid than energy-efficiency programs." (CPUC 2001). Although market penetration for DG units is slower than some had predicted, the use of these technologies continues to grow in California.

This anticipated growth has prompted legislation to create standards for DG equipment and its use. In 2000, California Senate Bill 1298 required ARB to establish uniform DG emission standards and a certification program for the DG technologies that are exempt from air pollution control or air quality management district permit requirements. The bill required that those standards match the ARB-determined best available control technology (BACT) levels for central station power plants at the earliest practicable date. In addition, ARB was required to develop guidelines for California air districts on permitting or certification of DG equipment that is less than 50 MW.

The Air Resources Board formed committees to help staff develop DG certification and guidance in the areas of applicability, the certification process, emission standards definitions, and source testing and emissions verification. It finalized and approved permitting and certification guidance for units that fall under air district jurisdiction and the certification program went into effect in October 2002 (ARB 2002). As of 2003, any DG technology that is exempt from district permit requirements must be certified by ARB before it can be sold in

California.[11] As of December 2007, six fuel cells and two microturbine had been certified. In addition, five fuel cells and one microturbine have "voluntary" certification.[12] Other states are also establishing permitting standards for DG equipment.

On a national level, the Regulatory Assistance Project (RAP)[13] led a collaborative effort of state utility regulators, state air regulators, state energy officials, DG manufacturers, and environmental advocates to draft model regulations for DG emissions standards for the National Renewable Energy Laboratory. The draft received public comment from a variety of DG manufacturers and government and environmental organizations, and it was completed in 2002 (RAP 2002). The model rule (which applies only to new installations) regulates NO_X, PM, CO, SO_2, and CO_2 and is based on the premise that the more a generator operates, the less its emissions per megawatthour must be. RAP also collaborated with the National Association of State Energy Officials (NASEO) to develop a Distributed Generation Policy Scoring Tool, which can be used to assess policy parameters relevant to DG deployment.[14]

3.3. DG Emissions: Impacts, Controls, and Research

3.3.1. Impacts from the Use of DG Technologies

Many studies conclude that substantial increases in air emissions would be likely if combustion DG systems were to take the place of modern, high-efficiency, combined-cycle power generation technology equipped with state-of-the-art air emissions controls. This is true because many of the most popular combustion DG technologies available are less efficient and produce emissions at a higher rate than modern, natural-gas-powered central station plants—or, in some cases, the California system average.[15] Compared to California's modern generating plants, a number of combustion DG systems can produce significantly higher air emissions of criteria pollutants, air toxics, and greenhouse gases (such as CO_2). Diesel engines with liquid fuels have the highest emissions profile; whereas, emissions from advanced fuel cells are anticipated to be relatively benign.

In fact, one report on DG and air quality concluded, in reference to fossil-fueled DG, that "…only the lowest emitting DG with significant waste heat recovery is even marginally competitive with combined cycle power production when air pollution issues are considered." (Lents and Allison 2000). The air quality impact of combustion DG technologies is strongly

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[11] This regulation was modified in 2006, and the revised version can be read at www.arb.ca.gov/energy/dg/2006dgreg.pdf.

[12] See the ARB Distributed Generation Program website at www.arb.ca.gov/energy/dg/dg.htm.

[13] Regulatory Assistance Project (RAP) is a nonprofit organization that conducts workshops and provides educational assistance to state public utility regulators on electric utility regulatory issues. For more information, see www.raponline.org/.

[14] Distributed Generation Policy Scoring Tool. www.raponline.org/Feature.asp?select=83&Submit1=Submit.

[15] Efficiencies among DG technologies vary considerably; therefore, some scenarios could reach a different conclusion.

influenced not only by the type and size of generator and fuel used, but also by the extent of capture and effective use of "waste heat" from the device (e.g., for heating, ventilation, and air conditioning or process applications) (Samuelson 2005). Using the heat from these units (either in the electricity generating process itself or to heat/cool water or air systems in nearby facilities) greatly increases their efficiency, but many emissions and system efficiency issues need to be better understood to maximize these process benefits.

Not only are emissions typically higher for many of these DG technologies, the units are also frequently sited in urban, highly populated areas and do not incorporate tall stacks to improve the dispersion of air emissions. As a result, nearby populations can experience greater health risks—both because these DG systems emit higher concentrations of some pollutants and because the emissions are at ground level (e.g., see Ryan et al. 2002). Without effective controls, these increased emissions could exacerbate health problems, particularly for sensitive populations.

The California Air Resources Board,[16] the National Defense Research Council,[17] and the Regulatory Assistance Project[18] have conducted numerous tests on the emissions and efficiencies of many DG technologies. However, these tests are several years (or more) old and have been conducted under laboratory conditions. Recent field testing data has indicated that emissions from DG units in the field may be many times higher than from a properly maintained unit. Results from one study of emissions from internal combustion engines (ICEs) in the South Coast Air Quality Management District showed that many of the ICEs were out of compliance because they did not have continuous emissions monitors.[19] Although some testing has been conducted on various DG units, additional testing is needed to adequately characterize current in-use DG technologies over the range of pollutants and operating conditions, including PM and toxics. Additionally, with new DG technologies including hybrids and CHPs entering the marketplace, it is necessary to conduct emissions testing on the newest generation technologies and those to be deployed in the near future.

The ARB's Diesel Risk Reduction Program addresses diesel emissions from all sources and has published both a risk management guidance document and a risk reduction plan for diesel technologies (ARB 2000a, 2000b). They built on that work by designing specific statewide guidance and regulations designed to further reduce diesel PM emissions from diesel-fueled engines and vehicles.

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[16] Iannucci, Joseph et al. June 2000. *Air Pollution Emission Impacts Associated with Economic Market Potential of Distributed Generation in California.* Distributed Utility Associates. (Numbers reflect units projected for 2002).

[17] Personal communication from NRDC to James Lents.

[18] Work conducted by Joel Bluestein for the Regulatory Assistance Project (RAP).

[19] SCAQMD. 2006. Emissions from In-Use IC Engine DG & Lessons Learned. PowerPoint presentation. www.energy.ca.gov/pier/conferences+seminars/2006-10-3+4_electricity_air-quality_conference/presentations/session_02/12Kay.ppt#256,1,Emissions from In-Use IC Engine DG & Lessons Learned.

In addition to emissions, there is a need to address the life-cycle impacts of DG technologies on the environment and the subsequent costs of those impacts. Similarly, although stand-alone DG units not connected to the electrical grid are hailed by some as an effective means of relieving grid congestion, evaluations of combustion DG technologies also need to consider the efficiency limitations and environmental implications of such technologies.

In summary, distributed generation systems analyses require an examination of the entire spectrum of DG technologies as they relate to the complete electric supply system. From the information that exists today it is clear that DG could have adverse impacts on air quality if not properly implemented. These air quality implications are highly dependent on what fuels they may use and whether their use displaces some other form of generation or energy use (and if so, the type and location of the generating or energy-using units that are being displaced). There are still significant gaps in our understanding of the efficiencies, in-use emissions, nearby emissions impacts on health, and life-cycle impacts of DG that are necessary to understand the full ramifications of various forms of DG implementation. This roadmap outlines these technical gaps and recommends research that will provide regulators with data that will enable them to guide the responsible implementation of DG in California.

3.3.2. Controls for DG Technologies

Combustion DG technologies typically have higher emissions than central station power plants because they are not required to have the most stringent emissions controls. However, this situation is changing and the regulatory authorities are beginning to require similar emissions levels for most DG. Controls for diesel DG units are being developed by a host of private companies. The ARB has surveyed controls manufacturers to identify technologies that reduce particulate emissions from diesel-fueled engines, and PIER-EA worked with the University of California (UC) at Riverside to measure emissions.

Historically, controls for non-diesel DG units have not been a high research and development priority, because the number of non-diesel DG generators has been relatively small, and natural gas (the most widely used non-diesel fuel) produces far less emissions than diesel generators. However, research is now beginning to be developed for natural-gas-fired DG.

3.3.3. Sampling and Analytical Protocols

The Association of State Energy Research and Technology Transfer Institutions (ASERTTI), in conjunction with Gas Technology Institute (GTI), Southern Research Institute (SRI), the Energy Commission, and others developed Distributed Generation Testing Protocols[20] for laboratory and field testing and monitoring. The protocols cover diesel-, natural gas-, and fuel cell-powered DG units, and they address CHP applications. Work by the Energy Commission, the Bourns College of Engineering – Center for Environmental Research and Technology (CE-CERT) at UC Riverside, and others resolved previous concerns about sampling and analytical

[20] ASERTTI website: Distributed Generation Testing Protocols and Performance Database with an Emphasis on Combined Heat and Power Applications. www.dgdata.org/

protocols for NO_X emissions (see Appendix A, project B1). However, the methods used for the NO_X work were unable to account for the ammonia used in the simulated exhaust when there was also CO_2 present in the simulated exhaust. The South Coast Air Quality Management District (SCAQMD) has developed a monitoring protocol[21] for its standards.[22] ARB has protocols for certifying new DG units.[23] Sampling and analytical protocols for emissions measurements may not be adequate to meet the ARB 2007 DG standards.

Existing regulatory testing methods for stationary combustion sources are known to underestimate or overestimate the contribution of the source to ambient aerosols, because they do not properly account for primary aerosol formation, which occurs after the gases leave the stack. Primary aerosols include both filterable particulate that is a solid at stack temperature and condensable particulate, which forms within a few minutes of exiting the stack. Dilution sampling systems have widely been used in research studies to characterize emissions, and there is a need to extend this technology. The University of California at Riverside is currently conducting a project addressing this issue.

New sampling and analytical methods may need to be developed to measure emissions from new DG technologies as they emerge.

3.3.4. Dispersion Modeling

Because DG units can be sited very near workplaces or residences and emissions from DG units can affect people who work and live in close proximity to these generating sources, determining how these emissions travel and where they are deposited is key to ensuring public health and safety. Dispersion models help researchers make such determinations.

However, the dispersion models currently in use in California lack two features necessary to determine emissions dispersions for DG units. First, they have not been validated for very close distances (less than 100 meters (328 feet) from the source). It appears that existing dispersion models are not capable of modeling reliably at distances less than 50 meters, because traditional Gaussian plume models are based on field studies where receptors were placed from 50 meters to 1,000 meters from the source. Second, they are inadequate for modeling dispersion in urban areas. The topographical variations inherent in urban areas and the resulting impacts on air flow greatly increase modeling complexity, and researchers are working to develop accurate models that can account for these variations.

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[21] South Coast Air Quality Management District. November 2007. Protocol for the Periodic Monitoring of Nitrogen Oxides, Carbon Monoxide, and Oxygen from Stationary Engines Subject to South Coast Air Quality Management District Rule 1110.2. http://www.aqmd.gov/rules/proposed/r1110_2/Protocol.pdf.

[22] South Coast Air Quality Management District. Proposed Amended Rule 1110.2 Emissions From Gaseous- and Liquid-Fueled Engines. www.aqmd.gov/rules/proposed/r1110_2/PAR1110.2Dec142007.pdf

[23] California Air Resources Board. Final Regulation Order Amendments to the Distributed Generation Certification Regulation. www.arb.ca.gov/energy/dg/2006regulation.pdf.

Both of these factors are important for modeling emissions from DG units, because such generating units are likely to be sited close to where people work and live—often in urban environments. From a regulatory perspective, these factors are necessary to support environmental justice analyses.[24]

In addition, accurate modeling depends on high-quality data inputs (including equipment, operational, and efficiency information from the operation of DG units, as well as data from emissions measurements). However, systems are not always in place to collect adequate information for some locations or technologies. For example, DG operators are not required to submit information to the Energy Information Administration (EIA) regarding DG equipment, fuel, cost, and other operating information. Although air districts and other sources can provide some of this information, similar information gathered by EIA for other generating equipment is far more comprehensive.

In January 2002, the Energy Commission and ARB jointly sponsored a workshop on short-range (up to 10 to 20 kilometers) dispersion modeling (TRW Systems 2002). The goal was to identify research that would help better assess environmental and health impacts attributable to DG units and central power plants and issues related to environmental justice. Accurate short-range dispersion models are necessary to assess exposure from DG units.

The workshop concentrated on four major subject areas of concern: (1) the urban environment, (2) meteorology and complex terrain, (3) the stable boundary layer, and (4) model and database evaluation. The workshop's specific objectives were to:

- identify the state-of-the-science for short-range dispersion modeling;
- identify the short-term (one- to three-year), mid-term (three- to ten-year), and long-term (ten- to 20-year) improvements necessary for short-range dispersion models to be able to estimate hourly and annual concentrations for inert (e.g., CO, SO_2, and PM) and reactive (e.g., NO_2) pollutants; and
- estimate the cost associated with the research to improve these models.

A select group of short-range dispersion modeling experts participated in the workshop, which consisted of separate sessions for each of the four subject areas mentioned above. An expert in each of the subject areas summarized the current status of that particular subject area, then all participants engaged in a general discussion as they reviewed the state-of-the-science, identified shortfalls in existing methodologies, and developed a list of recommendations to remedy those shortfalls. Relevant key recommended research needs are discussed in Section 4.

Data from the U.S. Department of Energy (U.S. DOE) URBAN 2000 study could help dispersion modelers evaluate those models over a broad range of atmospheric conditions. The U.S. DOE conducted tracer studies in and around Salt Lake City, Utah, to study an urban nocturnal boundary layer with stable to neutral conditions. The resulting datasets resolve interacting

[24] PIER-EA is also developing a roadmap on Environmental Justice.

scales of motion from tens of meters through 100 kilometers, all under the same meteorological conditions. A 2003 follow-on study examined the urban daytime boundary layer and other transport and dispersion factors.[25]

3.4. The PIER-EA Focus

Many of the PIER-EA efforts proposed by this roadmap build upon or interconnect with DG efforts conducted by other entities, both within the Energy Commission and with other research institutions. However, unique to the PIER Environmental Area is the specific focus on the research and development (R&D) efforts to understand the air quality impacts from the production and use of electricity in California. The California Air Resources Board has a broader task: to conduct R&D that will improve air quality by reducing emissions from a wide variety of stationary and mobile sources. Often, the work of these two agencies complements each other (particularly when conducting fundamental research), so ARB is a likely collaborative partner for much of this research. The PIER Environmental Area is redoubling its efforts to leverage R&D whenever possible, to lower research costs, benefit from combined expertise, and help ensure the applicability of project results.

The PIER Environmental Area has also identified environmental justice as a priority issue, and many of the activities recommended in this roadmap overlap with those recommended in the environmental justice roadmap that is being developed. The PIER Environmental Area will coordinate its DG and environmental justice activities to ensure that these efforts support one another.

The PIER Environmental Area will also work with other PIER areas whenever feasible. This roadmap outlines activities recommended by PIER-EA; however, other PIER areas also have projects that address DG issues. PIER-EA will collaborate with other PIER areas on those issues, and the DG focus of those areas is identified below:

- The PIER Renewables program funds and conducts activities that specifically address renewable DG technologies.
- PIER's Environmentally Preferred Advanced Generation (EPAG) area is also addressing various DG issues, some of which focus on air emissions from small industrial turbines, microturbines, reciprocating engines, and hybrid units. For example, EPAG established an Advanced Reciprocating Internal Combustion Engines (ARICE) collaborative that focuses on reducing DG emissions. The collaborative facilitates RD&D and commercialization of ARICE technologies and coordinates policy efforts with utilities, ARB, and other agencies to help advance the use of inexpensive, reliable, efficient, and clean DG technologies.
- The PIER Energy Systems Integration (ESI) program has also been conducting projects to address the successful implementation of DG in California, focusing on

[25] See Allwine et al. 2003. Overview of Joint Urban 2003 – An Atmospheric Dispersion Study in Oklahoma City. http://ams.confex.com/ams/pdfpapers/74349.pdf.

interconnection standards and technology, impacts of distributed energy resources on the electricity grid, and market integration of distributed energy resources. Together with EPRI they developed the Energy Commission's Distributed Energy Resources (DER) website,[26] which contains information usable by policy makers, consumers, and researchers. The PIER ESI program also developed a DG strategic research assessment report (CEC 2001a), with the intention of using that report for future solicitations.

4.0 Current Research and Research Needs

At present, research needs to focus on five areas to help ensure the growth of DG in California without adverse air quality impacts. These research areas are:

1. Air emissions inventory and characterization.
2. Dispersion modeling to identify local impacts.
3. Life-cycle assessments of DG technologies (including materials, emissions, fuels, and waste).
4. Emissions reduction technologies, fuels, and process improvements.
5. Comprehensive analyses of air quality impacts from distributed generation growth.

The following discussions outline the status of current work in these areas and identify scientific and research gaps.

4.1. DG Inventory and Air Emissions Characterization

Air emissions data research should focus on a better characterization of emissions associated with existing and future DG technologies. Until recently, little effort had been made to establish a statewide inventory of DG units that could be used to estimate the potential emissions from these technologies in California. PIER-EA began to address this issue by gathering information to establish an inventory of California BUGs greater than or equal to 300 kW (see Appendix A, project B4 and CEC 2001b). In addition, the PIER program sponsored a study to estimate the current and future inventory of DG CHP units[27] and has developed a roadmap for introducing future DG technologies.[28] Because of these projects, the current inventory of DG is now much better understood.

The Electric Power Research Institute (EPRI) has gathered emissions data from microturbines, Stirling engines, and reciprocal engines. However, the current ARB emissions testing protocols are inadequate to measure some pollutants at the ARB 2007 standards. There is a great deal of

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[26] California Energy Commission. Distributed Energy Resources. http://www.energy.ca.gov/distgen/.
[27] *Assessment of California CHP Market and Policy Options for Increased Penetration.* EPRI, Palo Alto, California, and California Energy Commission, Sacramento, California.2005. www.energy.ca.gov/2005publications/CEC-500-2005-173/CEC-500-2005-173.PDF.
[28] Rawson, Mark, and John Sugar. 2007. *Distributed Generation and Cogeneration Policy Roadmap for California.* CEC-500-2007.021. www.energy.ca.gov/2007publications/CEC-500-2007-021/CEC-500-2007-021.PDF.

uncertainty about the emissions characteristics associated with future DG technologies—in particular, their profile under field conditions, over extended time periods, and under suboptimal maintenance conditions. PIER-EA and EPRI have developed emissions testing and certification protocols for DG units (particularly small combustion turbines, fuel cells, and internal combustion engines) that will help ensure that all emissions data gathered on DG units is comparable and useful (see Appendix A, project B3). As part of the effort, researchers determined how to select a third-party test facility to ensure credible, repeatable results that will facilitate responsible DG implementation. ASERTTI has developed numerous testing protocols as well.[29]

The Electric Power Research Institute developed SOAPP CT2.5 software, which can help users evaluate emissions from combustion turbine power plant designs less than 28 MW in a site-specific context. It is designed to be used by electric utilities and developers to estimate cost, emissions, and performance issues of this equipment, so that they can determine which technologies to purchase and operate. Although it may be adaptable to perform the kind of broad emissions analyses discussed in this roadmap, it is not intended for that purpose, and its usefulness for regulators or other stakeholders is uncertain.

One problem that arises when characterizing emissions is having to rely on test methods that have not always been fully validated. For example, existing PM source test methods may be "overpredicting" emissions from natural gas combustion. The Energy Commission worked with GTI to address the inadequacies of the existing test methods and to identify weakness and problems with the current procedures (see Appendix A, project B7). Although this effort did not specifically test emissions from DG units, the method is applicable to DG technologies.

Research Needs

1. Research efforts also need to project the future market penetration of DG units in California (see 5.1.5.A).
2. Emissions assessments should be conducted for commercial technologies and potential technologies deemed likely to emerge in the next few years, to identify an emissions baseline for those units (see 5.1.2.A).
3. Emissions need to be measured in the field to help determine emissions changes over time and under varying maintenance conditions (see 5.1.1.C).
4. Emissions measurement protocols need to cover the full range of DG technologies (see 5.1.1.B).

4.2. Dispersion Modeling to Identify Local Impacts

Current dispersion models are unable to adequately model DG units in all environments. For example, existing models' predictive techniques provide unreliable estimates of the impact from

[29] Protocols can be found at an ASERTTI website: www.dgdata.org.

low-stack-height DG emissions—particularly the near-field concentrations of these emissions. A number of projects are under way to address the limitations of these models.

As mentioned in Section 3, the Energy Commission and ARB conducted a workshop on short-range dispersion modeling in early 2002. Several overarching recommendations were identified as high priority for all subject areas. These recommendations included the following:

1. Conduct a critical literature review of the state-of-the-science and existing datasets.
2. Conduct new, high-quality field studies to meet the current needs.
3. Evaluate existing dispersion models with existing and new datasets, and develop better model evaluation procedures.
4. Improve existing models.
5. Develop a formal framework to study model uncertainty and variability, to better understand the model behavior and to adopt a probabilistic approach in the decision-making process.
6. Form working groups to facilitate the exchange of ideas and to encourage development of new tools and methods to resolve the modeling issues identified.

The California Air Resources Board is evaluating and improving dispersion models as part of its neighborhood modeling efforts. It is using five dispersion models; choosing different models for different areas, based on the source type, spatial scale of model estimates, and type of terrain. The dispersion models are (1) ISCST3, the U.S. Environmental Protection Agency's (U.S. EPA's) currently recommended Gaussian model to estimate concentrations from point and area sources; (2) AERMOD, a model with an improved dispersion algorithm, that will replace ISCST3; (3) CALPUFF, an advanced U.S. EPA model for application in complex terrain; (4) CALINE, a roadway model; and (5) a Lagrangian stochastic model that is now being developed with UC Riverside.

The ISCST3 model is validated from 100 to 1000 meters (328 to 3280 feet) from a source, as are most of the U.S. EPA air dispersion models. The data used to formulate the ISCST air dispersion model is based on an old tracer study—the U.S. EPA Prairie Grass, Nebraska, study in 1956 (see Paine et al. 1998). The receptor sampling for Project Prairie Grass was from 50 m to 800 m from the source. With this data, dispersion curves were formulated from 50 m to 800 m from the source. Any study using the Project Prairie Grass data that is looking at emissions closer than 50 m and further than 800 m from the source is extrapolating the original data. The California Air Resources Board, as a matter of practice, is maintaining a minimum receptor distance of 20 meters from source to receptor for ISCST3, AERMOD, and CALPUFF applications.

To better understand the reliability of these models' results and the validity of their short-range capabilities, ARB is evaluating their performance. In cooperation with Dr. Akula Venkatram of UC Riverside, ARB is developing a dispersion algorithm for source-receptor distances of less than 50 meters. This study—which began at Barrio Logan near San Diego in 2001—will also include field tracer experiments to validate model predictions from various dispersion models in the near field. Researchers will release a nontoxic tracer gas (sulfur hexafluoride, or SF_6) from a known source, then use downwind samplers to measure the tracer gas concentrations in ambient air. Researchers will also collect samples from surface and upper level winds. The Energy Commission is co-sponsoring further field studies with ARB in Wilmington, in Los Angeles County. By comparing model estimates with measured tracer gas concentrations for different neighborhood areas and different meteorology, it will be possible to identify which dispersion models are the most reliable for short-distance modeling. The tracer database will be also used for developing a new dispersion algorithm for near-source impacts. The new algorithms will be tested with advanced models and then incorporated into regulatory dispersion models such as AERMOD.

Once ARB's dispersion model analyses are complete, efforts to improve dispersion models can proceed. However, expanded data gathering can begin sooner. Although ARB is evaluating dispersion models, these assessments will involve a small number of sites. Considering the high variability of dispersion within urban terrain, such assessments are expected to require field studies in a greater variety of locales.

To ensure that models provide results that are appropriate for regulatory decisions, research should evaluate model performance. One way to assess model performance is to analyze sources of uncertainty in air quality models and how those various sources of uncertainty affect confidence in model results. Analyzing model uncertainty can be useful for targeting model improvement efforts and for providing context to model results for the end-users of those results.

Fundamentally, an *air dispersion model* is a complex system of underlying models and input parameters that are mathematically integrated to develop modeling results. A *model component* can be defined as a group of related model input parameters or models. Each component can model an aspect of air dispersion independently, and each carries with it some degree of uncertainty. Modeling components may include emissions inventory, spatial and temporal allocation of emissions, meteorology, pollutant transformation, model physics and formulation, and deposition/removal processes. To understand uncertainty in air dispersion modeling results, one must develop a complete understanding of the sources of uncertainty in *each* modeling component. This task requires separating air dispersion modeling applications into discrete modeling components and analyzing uncertainty in each component individually. Then, Monte Carlo methods[30] must be applied to distributions developed for each model component, to estimate uncertainty in the entire modeling system.

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[30] A Monte Carlo analysis is a procedure that uses random numbers to simulate processes that involve chance, to arrive at a statistical conclusion.

The U.S. Environmental Protection Agency is currently sponsoring research to develop a comprehensive methodology for uncertainty analysis in model results.[31] This study's main focus is uncertainty analysis for the U.S. EPA's National Air Toxics Assessment. More research is needed to adapt this methodology for near-source impact analysis, specifically for DG risk assessment.

Research Needs

Research in this area needs to focus on four areas:

1. Conduct a critical literature review of the state-of-the-science and existing datasets. (see 5.1.2.A.)
2. Improve the ability of dispersion models to adequately model all DG-relevant environments. (see 5.1.2.A.)
3. Expand data gathering (e.g., through high-quality field studies) to extend databases for model evaluation and improvement of model algorithms (see 5.1.2.B). The acquisition of such field data are instrumental in developing and evaluating new theories and models. Well-designed field programs often lead to significant scientific progress; however, field studies are expensive. Accordingly, selected field studies should be conducted targeting areas of importance and uncertainty. Any new field experiment must have clearly defined scientific objectives and sufficient funding to allow for data analysis. (See 5.1.2.B.)
4. Because DG is likely to be deployed in residential areas and the air toxics from DG emissions might cause significant health risks, it is crucial to ensure that health risk estimates are accurate. Therefore, research needs to conduct uncertainty analysis for the modeling results. (See 5.1.2.C.)

4.3. Life-Cycle Assessments of DG Technologies

Life Cycle Assessment (LCA) is an analytical tool for environmental decision support that is in development worldwide. An LCA assessment, sometimes referred to as a "cradle-to-grave" assessment, evaluates the impacts from a product or technology over its lifespan.

Life Cycle Assessment consists of four iterative phases: (1) *Goal and Scope Definition,* which defines the aims, product system, and reach of the study; (2) *Inventory Analysis,* in which extractions and emissions related to the product system are quantified and related to the product function; (3) *Impact Assessment,* in which the inventory's outcome is analyzed with respect to its environmental relevance and is aggregated within a smaller number of relevant environmental issues; and (4) *Interpretation*, in which the results are compared with the goal of the study.

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[31] See the U.S. EPA's Quantification of Uncertainty in Air Quality Models Used for Analysis of Ozone Control Strategies program at http://cfpub.epa.gov/ncer_abstracts/index.cfm/fuseaction/display.abstractDetail/abstract/50.

To date, disparate research efforts have been conducted that could be used to piece together an LCA, but PIER-EA has been unable to identify any full-scale LCAs that have evaluated DG technologies.

Science Applications International Corporation (SAIC), with assistance from the National Association of State Energy Officials (NASEO) and support from U.S. DOE, developed a Distributed Generation Analysis Tool (version 1.0). This software enables users to conduct a 20-year life-cycle cost analysis and to assess the environmental impacts of DG technologies. Users input data and the analysis tool generates emissions and operating summaries, as well as financial analyses. It focuses on engines, turbines, microturbines, and fuel cells, and provides air emissions factors in pounds per kilowatthours (lb/kWh).

Research Needs

1. A life-cycle assessment of DG technologies is needed to evaluate all emissions related to the construction, operation, and disposal of these technologies in comparison to central power plants, and to assess the impact of these emissions on human and natural environments (see 5.1.3.A).

4.4. Emissions Reduction Technologies, Fuels, and Process Improvements

Emissions reduction technologies can control emissions of NO_X, CO_2, SO_X, PM, CO, VOC, and air toxics. As a rule, VOC and PM controls also control most toxics.

Existing control technologies are thought to be inadequate for at least some DG generating units and emissions (particularly for those technologies likely to be deployed in the near term); however, there is a lack of field performance data on existing controls. Similarly, researchers need more data on the efficacy of fuel composition and process improvements in real-world applications, to evaluate the effectiveness of these technologies.

Both the Energy Commission and ARB have conducted efforts to evaluate and improve emissions reduction technologies. However, such efforts have focused primarily on diesel-fueled portable and stationary units used for backup generation, and Energy Commission R&D efforts and studies have not expanded to controls, fuel composition, and process improvements such as CHP for non-diesel units used as primary electricity generators.

4.4.1. Emissions Reduction Technologies (Controls)

Identifying and characterizing existing controls is the first step toward developing better controls. The ARB's Toxic Air Contaminant program has conducted a technical evaluation of some commercial technologies for diesel engine emissions reduction. Criteria include availability, emission reduction efficiency, costs, adverse impacts, and other relevant factors. The ARB has also verified PM emission control devices for both stationary and mobile engines, and offers a list of those devices on its website.[32] Because the emissions potential for uncontrolled diesel units is high, effective controls for diesel engines are becoming commercially available, and emerging diesel-control technologies that would further decrease emissions and/or cost less to use are in development.

The ARB diesel risk-reduction program addresses control of PM and toxics.[33] The ARB also worked with PIER-EA to evaluate the effectiveness of particulate matter control technologies for stationary sources (see the UC Riverside BUGs project in Appendix A, B6).

4.4.2. Fuels

Fuel composition affects both a DG technology's efficiency and the quantity and composition of its emissions. Many public and private entities are conducting work to address emissions from diesel-fueled units, because they are the most widely used types, and they tend to produce high particulate emissions, which ARB has identified as toxic air contaminants. Many fuel studies have focused on *mobile* applications; however, most solutions could also be applied to *stationary* diesel applications. Current fuels work focuses on diesel water emulsion, Fischer Tropsch diesel fuel, and low-sulfur diesel (also known as EC diesel)—all of which can reduce NO_X and PM emissions.

For the most part, work on non-diesel DG fuels has been limited, primarily because of the lack of non-diesel units overall and because many use natural gas, which is already considered to be a relatively clean fuel.

4.4.3. Process Modifications

For this roadmap, *process modifications* means any physical change in the electricity generating process that enhances efficiency or reduces environmental impacts. For DG, the two most promising process modifications appear to be: (1) limiting the formation of compounds in the combustion process (through modifications such as the redesign of combustion chambers or the method used to deliver fuel to those chambers to make them more efficient), and (2) using integrated DG and CHP applications.

Process modifications can limit the formation of a compound before it is emitted, thus eliminating the need for end-of-pipe controls. The PIER Environmental Area has successfully demonstrated a comprehensive process modification strategy for reducing NO_X formation in industrial gas burners and stationary gas turbines by using sensors that provide feedback to adjust combustion variables that control NO_X formation (see Appendix A, project B2). Once this combustion strategy is refined, it could be used to prevent NO_X formation in DG units.

Studies have shown that DG units in CHP applications achieve far greater efficiency than when used outside of CHP configurations, and it is envisioned that to be environmentally friendly,

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[32] See the California Air Resources Board's verified diesel emission control strategies at www.arb.ca.gov/diesel/verdev/vt/cvt.htm.

[33] California Air Resources Board. California's Diesel Risk Reduction Plan. www.arb.ca.gov/diesel/dieselrrp.htm.

combustion DG will need to be coupled with CHP to the greatest extent possible. In fact, combined heat and power applications may result in reduced emissions, when considering the emissions from both the traditional heat generation source and electricity generation source. Distributed generation/CHP applications are currently in operation; however, most are aftermarket retrofits that do not achieve the efficiency and emissions that could be realized with truly integrated systems. One recent industry report claims that optimally balanced DG systems in CHP applications can achieve 90% system efficiency (Jackson 2003). Another report that examined performance and costs issues of natural-gas DG technologies focused on CHP applications on the assumption that the majority of future natural-gas DG installations would be used in CHP applications (TEF 2000). Efforts are currently under way to identify the real-world efficiencies and potentials of DG/CHP applications throughout California (see Appendix A, project A5). The PIER Environmentally Preferred Advanced Generation area has also been working to identify performance goals for turbines and reciprocating engines using CHP.[34]

Research Needs

1. There is a need to identify and characterize emissions reduction technologies for those non-diesel DG applications that are likely to experience high growth in the next decade. This work should include field measurements of toxics and PM speciation. (see 5.1.4.A)
2. In addition, field tests on emerging controls and new fuels are needed to confirm that they will work well with stationary units over time. PIER-EA and the University of California at Riverside are currently conducting work in this area. (see also 5.1.4.A)
3. If unavailable or inadequate, effective emissions controls, fuels, and other process improvements must be developed for DG units. (see 5.1.4.B)
4. Near-term process improvement research should focus on the environmental implications of connecting DG with CHP applications that can significantly boost generation efficiency and reduce emissions.

4.5. Comprehensive Analyses of Air Quality Impacts from Distributed Generation Growth

Distributed generation technologies will be used not only in *addition* to central generating plants, but also as a *replacement* for grid power. To be able to understand and manage the overall air emissions from the use of DG, analysts will need to understand which generating sources these units may replace, where those sources are located, what fuels they may use, and how they may operate throughout the year.

Some studies have evaluated the emissions impacts from a potential increase of DG use in California; however, there have been no comprehensive electricity system studies analyzing DG implementation in the state and its overall effect on both the electricity system and emissions. To determine the effect on the state's electricity grid and air quality, such an analysis would

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[34] PIER Environmentally Preferred Advanced Generation Research Plans. www.energy.ca.gov/pier/epag/research.html.

have to identify which DG technologies are likely to be used in California and also assess how those technologies would be used. A previous ARB study examined the effect of DG technologies on air emissions in the state, but it examined the technologies *individually*, rather than focusing on the entire *portfolio* of generating options and how their use (combined with central generating plants) would affect air emissions.

The Energy Commission and the University of California, Irvine, are conducting ongoing a projects to determine the environmental impact of widespread DG deployment in Southern California. The work is addressing modeling issues (particularly the role of aerosols in modeling) and is being coordinated with the modeling efforts of ARB, the South Coast Air Quality Management District (SCAQMD), the Southern California Ozone Study, and the Central California Air Quality Study (see Appendix A, project A3). The Energy Commission also conducted a project with UC Riverside, to evaluate the environmental impacts of various BUG implementation scenarios in California. (see Appendix A, project B6). Currently, the Energy Commission is working with UC Riverside to improve the near-term air quality impact of DG located in urban areas. (see Appendix A, project A2).

A study conducted by Distributed Utility Associates for ARB evaluated methods for conducting scenario analyses and identified data that could be used to quantify the likely effect of DG on California air emissions (Iannucci et al. 2000). The resulting report concluded that analysts could use both the emissions rates of individual DG technologies and the average emissions of grid-connected units to estimate net increases or decreases in statewide emissions from the use of DG technologies. It also concluded that the increased use of DG in California would increase net emissions in the state in the near term. In addition, the study calculated the net air emissions effects from the potential use of DG technologies likely to be added in California in the next decade. That study included microturbines, Advanced Turbine Systems (ATS), combustion turbines, diesel engines, dual-fuel engines, Otto/spark engines, phosphoric acid fuel cells, and proton exchange membrane (PEM) fuel cells.

Studies outside California also contribute to comprehensive analyses of DG implementation. For example, the Center for Clean Air Policy—a small nongovernmental organization that works to develop solutions to local and global air pollution—conducted a study that modeled air emissions from medium-sized CHP district energy systems. The Center built on that work by developing and running an electricity dispatch model that models the air emissions impacts of increasing DG penetration. This Distributed Resource Net Emissions Model (DR NEMO) models new DG capacity based on a technology diffusion model derived from the National Energy Modeling System (NEMS) and implemented in the Natural Resources Defense Council's Distributed Resources Emissions Model (DREM). The Center's work examined the penetration of DG technologies, their environmental and economic impacts, and their impact on new central station capacity. In another example, a Distributed Utility Associates study evaluated NO_X emissions from three different scenarios of DG implementation in Texas (Iannucci et al. 2002).

The Energy Foundation (TEF), a partnership of major foundations interested in sustainable energy, has also examined emissions from DG units. A report published in 2000 examines DG emissions levels and recommends a framework for DG emissions regulations (Lents and Allison

2000). A more recent study projected cost and performance information for DG/CHP technologies with emission controls over the next decade, using ARB's distributed generation emission certification regulations for 2003 and 2007 as benchmarks (TEF 2002).

To conduct an accurate assessment of system and emissions impacts, it is essential to predict the type and number of DG units that will be used in California. Lawrence Berkeley National Laboratory (LBNL) has developed a Distributed Energy Resources Customer Adoption Model (DER-CAM)[35] that helps users estimate and incorporate the penetration of distributed generation technologies into PIER's proposed modeling scenarios. Lawrence Berkeley National Laboratory used DER-CAM to model a hypothetical scenario for small strip mall in San Diego (Marnay et al. 2001). Another LBNL project combined DER-CAM analysis with a geographic information system (GIS) analysis of local land use constraints that would inhibit the use of DG, to better identify DG adoption patterns (Edwards 2002). Lawrence Berkeley National Laboratory updated the DER-CAM technology database in early 2004 (Firestone 2004).

Research Needs

1. Building upon the studies and ongoing efforts mentioned above to estimate the likely penetration of DG in California, research should assess the resulting emissions and environmental impacts from that system of generating units. Such an assessment should include modeling air emissions under various scenarios and conducting trend and scenario analyses to identify how these units are used. (See 5.1.5.A).

5.0 Goals

The goal of the PIER-EA Distributed Generation research is to help California benefit from the advantages of DG while ensuring that emissions from DG units do not further degrade air quality.

The achievement of that goal depends on improvement of the methods, tools, and data used to estimate impacts of distributed energy technologies on air quality. Technical air quality advisors provide ongoing input for this research and the five related research areas identified in the previous section.

The PIER-EA program recognizes that much work is currently under way in these areas and seeks to draw from, build upon, and broaden the focus of those efforts. Whenever possible, PIER-EA will identify existing efforts and form partnerships to leverage resources.

[35] DER at LBNL. See http://der.lbl.gov/new_site/DER.htm.

5.1. Short-Term Objectives[36]

5.1.1. Air Emissions Data

A. **Assess emissions of future DG systems (e.g., size and type of generator, application, fuel, use of waste heat, and efficiency) likely to be installed in the 1–10 year time frame. Likely technologies include microturbines, small gas turbines, fuel cells, internal combustion engines, diesel engines, photovoltaics, and wind turbines. ($500K)**

Activity needed: Assemble baseline operational and emissions data from manufacturer specifications and studies (e.g., the Energy Commission/University of California, Irvine studies).

B. **Support the development and standardization by ARB and the air districts of criteria pollutant test protocols that are capable of more accurately measuring lower emissions. ($600K*)**[37]

Activities needed: (1) Support the evaluation of criteria pollutant test protocols currently in use in California, building on the PIER-EA/GTI research on PM source test methods and the Energy Commission/UC Riverside research studying the measurement of very-low-NO_X concentrations. (2) Identify the shortcomings of the targeted protocols with respect to regulated pollutant levels. (3) Identify promising methods of measuring pollutants at regulated levels, and support the development of measurement techniques, procedures, and test cycles that accurately measure emissions from existing systems. (4) Test promising methods.

C. **Determine emissions profiles of existing and emerging DG systems and degradation of units through a review of manufacturers' data and by measuring air emissions (criteria pollutants and toxics) under actual field operating conditions and determining emissions changes over time. ($500K*)**

Activities needed: (1) Begin to determine emissions profiles of the identified systems through a review of manufacturers' data and a literature review. (2) Using one of the methods identified in Section B, and in coordination with other groups' efforts, measure air emissions for California DG units in the field to determine their emissions characteristics (criteria pollutants and toxics).

Critical Factors for Success:

- To establish a sufficient inventory of DG systems, researchers and regulators must have access to equipment, operational, and efficiency information.

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[36] S*hort-term* refers to a 1–3 year time frame; *mid-term* to 3–10 years; and *long-term* to 10–20 years. The activities specified in the roadmap are projected to begin sometime within the designated time frames, and the duration of actual projects may be less than the entire term specified.

[37] An asterisk (*) indicates a high probability that the work will be leveraged with other ongoing efforts. The figure given is the California Energy Commission's projected expenditure.

- Sampling and analytical protocols must be capable of accurately measuring the emissions from DG units at regulated levels. (See Objective 5.1.1.B.)
- PIER-EA-funded efforts must be coordinated with entities developing air quality regulations, so that the protocols and data will be used.
- Test protocols and methodologies must be accepted by researchers, regulators, and other stakeholders.
- DG developers and manufacturers must provide accurate operational and emissions data for emerging DG products.

5.1.2. Dispersion Modeling

A. **Evaluate and improve existing modeling techniques and databases to predict the dispersion of emissions on ground level concentrations.** (Work will be coordinated with Energy Commission/UC Riverside and ARB efforts already under way (see Appendix A, Energy Commission project A2 and ARB project 1), and will focus on near-source (50–100-meter) emissions, release characterizations, and obstructions.) **($450K*)**

Activities needed: (1) Evaluate existing dispersion models and databases to determine their ability to predict the dispersion of emissions on ground-level concentrations, with an emphasis on near-source emissions. This work will build on ARB's assessment of dispersion models in its neighborhood modeling efforts and development (with UC Riverside) of a dispersion algorithm for source-receptor distances of less than 50 meters. (2) If necessary, identify how dispersion models need to be modified to predict near-field dispersion of emissions on ground-level concentrations. (3) Based on the dispersion model evaluation, begin modification of an existing dispersion model to develop a sophisticated near-source (50–100-meter) dispersion model that can be used to accurately model dispersion on ground level concentrations. (4) Use the improved dispersion models to model neighborhoods affected or potentially affected by DG power facilities.

B. **Conduct selected dispersion modeling field studies to develop and evaluate new theories and models. ($400K*).**

Activities needed: (1) Review existing field studies to determine which areas need additional field work (e.g., in flat and complex terrain). (2) Conduct new field studies in major Californian cities with mesoscale and microscale meteorological networks to assess impacts attributable to individual distributed generation units.

C. **Conduct uncertainty analysis of dispersion modeling results. (Work will be coordinated with U.S. EPA efforts already under way.) ($200K*)**

Activities needed: (1) Adapt the U.S. EPA-developed methodology for analyzing uncertainty in model results so that it is applicable to near-source dispersion modeling. (2) Conduct an uncertainty analysis for a series of case studies to identify a potential range of uncertainties in modeled ground-level concentrations of toxic air pollutants resulting from DG. (3) Identify major components of uncertainty and find ways for improvement.

Critical Factors for Success:

- Dispersion models must be accepted by researchers, regulators, and other stakeholders.

5.1.3. Life-Cycle Assessment

A. **Conduct a life-cycle assessment (LCA) of DG Technologies. ($750K*)**

Activities needed: (1) Review existing LCAs of energy generating technologies. (2) Conduct a LCA of DG technologies and compare to impacts from a state-of-the-art combined-cycle, natural gas, central power plant.

Critical Factors for Success:

- Analysis must include multimedia effects.
- Analysis must examine the entire life cycle, from cradle to grave
- LCA for DG must be compared to impacts from a state-of-the-art combined cycle natural gas central power plant.
- Analysis must include all existing DG technologies and any expected to be available within the next 10 years.
- Analysis must include impacts to all relevant locations (i.e., local and distant).

5.1.4. Emissions Reduction Technologies, Fuels, and Process Improvements

A. **Evaluate the environmental performance of DG emissions reduction technologies, fuels, and efficiency improvements from heat recovery and other process improvements. ($700K*)**

Activities needed: (1) Through field tests and other means, evaluate and characterize the environmental performance of emissions controls and fuels for DG units. Field tests should measure toxic emissions and determine PM speciation. (2) Through field tests and other means, evaluate and characterize the environmental performance of emissions controls, CHP applications, and other process improvements currently being used on and developed for all DG units in California. Field tests should measure toxic emissions and determine PM speciation. (3) Based on the information gained in activity 2 above, identify the most efficient control and mitigation strategies. PIER-EA efforts will also focus on determining the status of emissions controls from non-diesel DG sources.

B. **Coordinate with other PIER areas and commercial developers to initiate the development of necessary controls, fuels, and other process improvements for DG options that are likely to be used on a widespread basis in the near term. ($500K*)**

Activities needed: In coordination with other PIER areas, initiate the development of control technologies needed for DG units in use or likely to be in use in the near term.

Critical Factors for Success:

- PIER-EA-funded efforts must be coordinated with the private sector developing DG units and controls for DG units, so that the data and tools will be used.

5.1.5. Comprehensive Analyses of Air Quality Impacts from Distributed Generation Growth

A. **Project the future use of specific DG technologies in the state, to assess the future air emissions from these technologies.** (This project would build upon the Energy Commission/UC Irvine analyses and Energy Commission/UC Riverside environmental impact assessments [see Appendix A, projects A2 and A3] and would coordinate efforts with other PIER areas [particularly the EPAG and ESI areas] that are addressing broader DG issues, such as efficiency improvements and the interconnection and market penetration of DG units. It could also use the ESI area's value network assessment of DG to help focus the analysis [CEC 2003b].) **($450K)**

Activities needed: (1) Use survey and market data to begin to project the future use of specific DG technologies in the state. (2) Using the projected penetration data of DG systems in California, model resulting air emissions under likely operating scenarios.

Critical Factors for Success:

- Analysis will need to include the many promising DG technologies that are pre-commercial or still in development. Unknowns associated with the timing and extent of DG market penetration—including factors such as equipment type, size, fuel, operating modes, and control technologies must be considered. Expert input, such as that provided by the Technical Advisory Committee will be instrumental in helping PIER-EA determine the commercial entry of emerging technologies.
- To evaluate the air quality impacts of DG technologies accurately, research planning for these units must consider each DG technology, as well as the fuel, use of "waste heat" in CHP applications, emission control effectiveness, and the emissions characterization of the generating technology that it may be replacing.

Table 1. Short-Term Budget

Objective	Projected Cost ($000)
5.1.1.A Assess emissions of future DG systems	500
5.1.1.B Support the development and standardization of criteria pollutant test protocols	600*
5.1.1.C Determine emissions profiles of existing and emerging DG systems and degradation of units	500*
5.1.2.A Evaluate and improve dispersion modeling techniques	450*
5.1.2.B Conduct selected dispersion modeling field studies	400*
5.1.2.C Conduct uncertainty analysis of dispersion modeling results	200*
5.1.3.A Conduct life-cycle assessment of DG technologies	750*
5.1.4.A Evaluate the performance of DG emissions reduction technologies, fuels, and efficiency improvement	700*
5.1.4.B Initiate development of necessary controls, heat recovery technologies, and other process improvements	500*
5.1.5.A Project the future use of specific DG technologies	450
Total Short-Term Cost	**5,050**

Note: An asterisk (*) indicates a high probability that the work will be leveraged with other ongoing efforts. The figure given is the California Energy Commission's projected expenditure to complete the short-term work.

5.2. Mid-Term Objectives

5.2.1. Air Emissions Data

A. **Develop and track the DG inventory (e.g., size and type of generator, application, fuel, use of waste heat, and efficiency) .**

Activities needed: (1) Develop a method to survey new owners of DG systems for generator, application, fuel, operational, and efficiency information and develop a California-specific inventory. (2) Determine emissions characteristics of any new installed DG technologies.

B. **As a continuation of activities started under the Air Emissions Data short-term objective, assess likely DG systems (e.g., size and type of generator, application, fuel, use of waste heat, and efficiency) to be installed in the 3–20 year time frame.** [Continuation of short-term work.]

Activities needed: (1) Based on Energy Commission/UCI DG analyses and other similar efforts, determine which pre-commercial systems are likely to be installed in the near term for the mid-term time frame. (2) Assemble baseline operational and emissions data on systems likely to be commercialized in the mid-term time frame from manufacturer specifications. (3) Identify DG technologies and their characteristics that are likely to be available in the long-term.

C. **For DG units that reached commercial maturity after the short-term work was performed, support the development and standardization of criteria pollutant test protocols that are**

capable of more accurately measuring lower emissions. Coordinate this work with other PIER areas.

Activities needed: (1) Support the evaluation of the test methods used to measure air emissions for mid-term DG units in California, to identify inadequacies. (2) If necessary, support the development of measurement techniques, procedures, and test cycles that accurately measure emissions from these mid-term systems. (3) Test the methods.

D. **Initiate measurement of air emissions (criteria and toxic), efficiency, and waste heat use under actual field operating conditions. Coordinate this work with other PIER areas.** [Continuation of short-term work.]

Activities needed: (1) Using the measurement techniques, procedures, and test cycles developed in the short-term work, continue to measure air emissions from units in the field, both for newer units and for those measured in the field under 5.1.1.C.

5.2.2. Dispersion Modeling

A. **Continue to collaborate with ARB to modify and improve dispersion modeling to develop a sophisticated near-source (50–100-meter) dispersion model that can be used to more accurately model dispersion on ground level concentrations.** [Continuation of short-term work]

Activities needed: Assuming further dispersion model modifications are necessary and possible, continue to collaborate with ARB to modify an existing dispersion model to develop a sophisticated near-source (50–100-meter) dispersion model that can be used to accurately model dispersion on ground-level concentrations.

B. **Based on the conclusions of the short-term work and 5.2.2.A, modify an existing dispersion model to develop a *simple, inexpensive*, near-source (50–100-meter) dispersion model that can be used by planners and other stakeholders for screening-level assessments.**

Activities needed: (1) Assuming modifications are necessary and possible, modify an existing dispersion model to develop a simple, inexpensive near-source (50–100-meter) dispersion model that can be used by planners and other stakeholders for screening-level assessments.

C. **Continue to conduct selected dispersion modeling field studies to develop and evaluate new theories and models.** [Continuation of short-term work.]

Activities needed: (1) Continue to review existing field studies to determine which areas need additional field work. (2) Conduct new field studies in major Californian cities with mesoscale and microscale meteorological networks, to assess impacts attributable to individual distributed generation units.

D. **Continue to conduct uncertainty analysis of dispersion modeling results.** [Continuation of short-term work.]

Activities needed: (1) Conduct an uncertainty analysis for a series of case studies, to identify a potential range of uncertainties in modeled ground-level concentrations of toxic air pollutants resulting from DG. (2) Identify major components of uncertainty and find ways for improvement.

5.2.3. Life-Cycle Assessment

A. **Conduct a life-cycle assessment (LCA) of DG Technologies.** [Continuation of short-term work.]

Activities needed: (1) Conduct an LCA of DG technologies that were not included in the short-term assessment (5.1.3.A).

5.2.4. Emissions Reduction Technologies, Fuels, and Process Improvements

A. **Build upon the earlier emissions reduction technologies, fuels, and process improvements development efforts.** [Continuation of short-term work.]

Activities needed: (1) Assess new data on mid-term to long-term DG technologies, to identify the need for controls, heat recovery technologies, and other process improvements. (2) Continue to coordinate with other PIER areas to initiate the development of control technologies for DG units in use or likely to be in use in the near term. (3) Continue to coordinate with other PIER areas to initiate the development of heat recovery technologies and other process improvements. (4) Continue to coordinate with other PIER areas to initiate the development of fuels that would improve air quality performance for DG units in use or likely to be in use in the mid term.

B. **Evaluate actual degradation of emissions reduction technologies against the baseline developed in the short-term work, to determine if the equipment meets manufacturers' expectations.**

Activities needed: (1) Gather emissions from a representative number of each DG technology type installed in California. (2) Compare sample emissions data with the baseline data gathered in the short-term work, to evaluate degradation. (3) Evaluate process improvements against baseline estimates to judge their effectiveness over time.

C. **Establish the current status of the performance of mid-term DG emissions reduction technologies, fuel developments, and efficiency improvements from heat recovery and other process improvements.**

Activities needed: (1) Survey emissions controls, heat recovery technologies, and other process improvements being used on California DG units that have been installed in the mid-term. Coordinate with other PIER areas.

5.2.5. Comprehensive Analyses of Air Quality Impacts of Distributed Generation Growth

A. **Continue to project the future use of specific DG technologies in the state to assess the future air emissions from these technologies. This project would continue to coordinate efforts with other PIER areas that are addressing broader DG issues.** [Continuation of short-term work]

   Activities needed: (1) Use survey and market data from Energy Commission/UCI system implementation analyses, environmental impact data from Energy Commission/UCR analyses, and other efforts to continue to project the future use and environmental impact of specific DG technologies in the state. (2) Using survey data of the currently installed DG systems in California, model resulting air emissions under likely operating scenarios.

A. **Determine the emissions of DG technologies installed in the state.**

   Activities needed: (1) Conduct trend and scenario analyses to determine how installed units are actually used and their impact on emissions. This activity would build upon survey data from previous PIER-EA activities and the efforts of other organizations such as the University of California at Irvine, the University of California at Riverside, and E2I.

5.3. Long-Term Objectives

5.3.1. Air Emissions Data

A. **Assess new and evolutionary DG systems (e.g., size and type of generator, application, fuel, use of waste heat, and efficiency) to be installed in the 10–20-year time frame and beyond, and initiate measurement of air emissions (criteria and toxic), efficiency, and waste heat use under actual field operating conditions.** [Continuation of mid-term work.]

   Activities needed: (1) Using the method identified in the short-term work, survey owners of new and evolutionary DG systems for generator, fuel, operational, and efficiency information. (2) Determine emissions characteristics of any new DG technologies installed in the long-term time frame. (3) If necessary, develop additional or improved measurement techniques, procedures, and test cycles.

5.3.2. Dispersion Modeling

A. **Continue to collaborate with ARB to modify and improve dispersion modeling to develop a sophisticated near-source (50–100-meter) dispersion model that can be used to more accurately model dispersion on ground level concentrations.** [Continuation of short- and mid-term work.]

   Activities needed: Assuming further dispersion model modifications are necessary and possible, continue to collaborate with ARB to modify an existing dispersion model to develop a sophisticated near-source (50–100-meter) dispersion model that can be used to accurately model dispersion on ground-level concentrations.

B. Based on the mid-term work, continue to modify an existing dispersion model to develop a *simple, inexpensive* near-source (50–100-meter) dispersion model that can be used by planners and other stakeholders for screening-level assessments. [Continuation of short- and mid-term work.]

Activities needed: (1) Assuming modifications are still necessary and possible, continue to modify an existing dispersion model to develop a simple, inexpensive near-source (50–100-meter) dispersion model that can be used by planners and other stakeholders for screening-level assessments.

C. Continue to conduct selected dispersion modeling field studies to develop and evaluate new theories and models. [Continuation of short- and mid-term work.]

Activities needed: (1) Continue to review existing field studies to determine which areas need additional field work. (2) Conduct new field studies in major Californian cities with mesoscale and microscale meteorological networks, to assess impacts attributable to individual distributed generation units.

D. Continue to conduct uncertainty analysis of dispersion modeling results. [Continuation of short- and mid-term work.]

Activities needed: (1) Conduct an uncertainty analysis for a series of case studies, to identify a potential range of uncertainties in modeled ground-level concentrations of toxic air pollutants resulting from DG. (2) Identify major components of uncertainty and find ways for improvement.

5.3.3. Life-Cycle Assessment

A. **Conduct a life-cycle assessment (LCA) of DG Technologies.** [Continuation of mid-term work.] **($500K*)**

Activities needed: (1) Continue to conduct LCAs of new DG technologies that were not addressed in earlier efforts.

5.3.4. Emissions Reduction Technologies, Fuels, and Process Improvements

A. **Coordinate with other PIER areas to initiate development of necessary controls, fuels, and other process improvements for DG options that are likely to be used on a widespread basis in the long-term time frame.** [Continuation of short- and mid-term work.]

Activities needed: (1) Assess information on the various DG technologies to emerge in the long-term time frame, to identify the need for control and process improvements. (2) If necessary, initiate development of emerging DG technology controls. (3) If necessary, initiate development of heat recovery technologies for emerging DG technologies.

B. **Evaluate actual degradation of the emissions reduction technologies, and process improvements for mid-term DG generators against the baseline developed in the mid-term work, to determine if the equipment continues to meet manufacturers' expectations.** [Continuation of short- and mid-term work.]

Activities needed: (1) Sample emissions from a representative number of each DG technology installed in California. (2) Compare sample emissions data with the baseline data gathered in the mid-term work to evaluate degradation. (3) Evaluate process improvements against baseline estimates to judge their effectiveness over time.

6.0 Leveraging R&D Investments

6.1. Methods of Leveraging

Much of the work identified in this roadmap would be collaborative with other entities; PIER-EA would either co-fund projects by other entities, or use outside funds to support PIER-EA efforts. Specifically, this roadmap seeks to:

- provide PIER funds for co-funding existing or planned work by ARB, EPRI, the University of California, and the Center for Clean Air Policy; and
- solicit funds from U.S. DOE and U.S. EPA to build upon their efforts, or to co-design new projects at the Energy Commission.

6.2. Opportunities

Co-sponsored efforts are already under way with UC Riverside, EPRI, GTI, UC Irvine, and ARB. Co-sponsorship opportunities are likely with ARB, the Center for Clean Air Policy, U.S. DOE, and U.S. EPA. Each of these organizations is interested in addressing air quality issues related to the implementation of DG in California. The following specific collaborative opportunities have been identified:

- PIER-EA will pursue cooperative efforts to help achieve DG goals shared with those in ARB’s Clean Air Plan.
- Dispersion modeling will be coordinated with ARB’s Neighborhood Assessment Program and the U.S. EPA’s modeling program.
- Uncertainty analysis will be coordinated with U.S. EPA’s development of a comprehensive methodology for uncertainty analysis.
- PIER-EA could work with the Center for Clean Air Policy to use the DR NEMO dispatch model to model potential air emissions from a greater use of DG equipment in California.
- PIER-EA could evaluate U.S. DOE’s “Strategic Plan for Distributed Energy Resources,” to identify potential co-sponsorship opportunities.
- Coordinate dispersion modeling efforts with the PIER-EA environmental justice efforts.
- Coordinate the development of necessary control and heat recovery technologies for diesel units with PIER’s EPAG area, ARB, U.S. DOE, EPRI, and others.

- Coordinate DG research activities with California regulatory agencies to ensure regulatory acceptance of the data, methods, and technologies developed through this effort.
- Explore the potential benefits of working with the California Alliance for Distributed Energy Resources (CADER).

7.0 Areas Not Addressed by This Roadmap

This roadmap addresses a wide variety of DG issues; however, it focuses on the *air quality* aspects of those issues only.

This roadmap does not directly address the technical development of new DG technologies, because such development is outside the scope of the PIER Environmental Area. It is being addressed by the EPAG area of the PIER Program.

This roadmap does not examine the non-environmental issues of DG implementation; however, other PIER areas are focusing on those issues. For example, the PIER ESI area developed a strategic research assessment report on distributed energy resources that examines a variety of DG issues (CEC 2001a). They also conducted a business model assessment that examined the value that DG can provide to California consumers, what service offerings DG providers might provide to consumers to realize those benefits, and the potential market/regulatory drivers that would enable the state to benefit from the use of DG technologies.

8.0 References

ARB (California Air Resources Board). 2000a. *Risk Reduction Plan to Reduce Particulate Matter Emissions from Diesel-Fueled Engines and Vehicles.* October. See www.arb.ca.gov/diesel/dieselrrp.htm.

ARB. 2000b. *Risk Management Guidance for the Permitting of New Stationary Diesel-Fueled Engines.* October. See www.arb.ca.gov/diesel/dieselrrp.htm.

ARB. 2002. *Guidance for the Permitting of Electrical Generation Technologies.* Stationary Source Division. Project Assessment Branch. July. See www.arb.ca.gov/energy/dg/dg.htm.

California Energy Commission (CEC). 2001a. *PIER Strategic Program – Strategic Distributed Energy Resources Research Assessment*. Consultant Report. P600-01-016. PIER Strategic Program. Sacramento, California.

CEC. 2001b. *Inventory of Backup Generators in the State of California.* P500-01-027. Sacramento, California. December.

CEC. 2002. *Distributed Generation Strategic Plan*. P700-02-002. Sacramento, California.

California Energy Commission. 2003a. *California Interconnection Guidebook: A Guide to Interconnecting Customer-owned Electric Generation Equipment to the Electric Utility*

Distribution System Using California's Electric Rule 21. P500-03-083. www.energy.ca.gov/distgen/interconnection/guide_book.html.

CEC. 2003b. *Identifying Distributed Energy Resources Research Priorities Through Emerging Value Networks*. P500-03-020C. PIER Energy Systems Integration Research Program. Sacramento, California. March.

CEC. 2005. *Identifying Distributed Energy Resources Research Priorities Through Emerging Value Networks*. CEC-500-2005-207. PIER Energy Systems Integration Research Program. Sacramento, California. December.

California Public Utilities Commission (CPUC). 2001. *Public Financing for Self-Generation: Costs and Benefits of Onsite Photovoltaic, Fuel Cell, and Micro-turbine Systems.* Office of Ratepayer Advocates. January.

Catalytica Energy Systems, Inc. 2005. *Xonon Ultra Low-NOx Combustion Applied to Multi-Combustor Gas Turbines.* Public Interest Energy Research. CEC-500-2005-174.

CPUC, CEC, and California Power Authority. May 8, 2003. *Energy Action Plan.*

Edwards, J., C. Marnay, E. Bartholomew, B. Ouaglal, A. Siddiqui, and K. LaCommare. 2002. *Assessment of µGrid Distributed Energy Resource Potential Using DER-CAM and GIS.* LBNL-50132. January. www-library.lbl.gov/docs/LBNL/501/32/PDF/LBNL-50132.pdf.

EPRI. 2000. *Emissions Testing and Certification Guidelines for Distributed Generators.* EPRIsolutions. Palo Alto, California.

Firestone, Ryan. 2004. *Distributed Energy Resources Customer Adoption Model Technology Data.* Lawrence Berkeley National Laboratory.

Greenberg, S. J. (Alzeta Corporation). 2000. *Alzeta Report on Low NOx Gas Turbine Combustors for Distributed Power Generation.* California Energy Commission, PIER Program.600-01-002.

Haynes, Rusty, and Chuck Whitaker. 2007. *Connecting to the Grid: A Guide to Distributed Generation Interconnection Issues.* Fifth ed. Interstate Renewable Energy Council (IREC) p. 24. www.irecusa.org/fileadmin/user_upload/ConnectDocs/IC_Guide.pdf.

Iannucci, Joseph et al. 2000. *Air Pollution Emission Impacts Associated with Economic Market Potential of Distributed Generation in California.* Distributed Utility Associates. June.

Iannucci, J., S. Horgan, J. Eyer, and L. Cibulka. 2002. *Analysis of NOx Emissions Limits for Distributed Generation in Texas.* Distributed Utility Associates. June.

Jackson, J. 2003. "Applying Distributed Generation Strategies to Ease the Long Island Power Crisis." Jackson Associates. January.

Lents, J., and J. E. Allison. 2000. *Can We Have Our Cake and Eat It, Too? Creating Distributed Generation Technology to Improve Air Quality.* The Energy Foundation. December. www.ef.org/downloads/.

Marnay, C., J. S. Chard, K. S. Hamachi, T. Lipman, M. M. Moezzi, B. Ouaglal, and A. S. Siddiqui. 2001. *Modeling of Customer Adoption of Distributed Energy Resources.* LBNL-49582. August. http://eetd.lbl.gov/ea/CERTS/pdf/LBNL_49582.pdf.

National Association of Regulatory Utility Commissioners (NARUC). 2003. *Model Interconnection Procedures and Agreement for Small Distributed Generation Resources.* NARUC. Washington, D.C. http://files.harc.edu/Sites/GulfCoastCHP/Publications/ModelInterconnectionProcedures.pdf.

Paine, R. J., R. F. Lee, R. Brode, R. B. Wilson, A. J. Cimorelli, S. G. Perry, J. C. Weil, A. Venkatram, and W. Peters. 1998. *Model Evaluation Results for AERMOD*. U.S. Environmental Protection Agency. Washington, D.C.

Regulatory Assistance Project (RAP). 2002. *Model Regulations for the Output of Specified Air Emissions from Smaller-Scale Electric Generation Resources.* www.raponline.org/ProjDocs/DREmsRul/Collfile/ModelEmissionsRule.pdf.

Ryan, N., K. Larsen, and P. Black. 2002. *Smaller, Closer, Dirtier: Diesel Backup Generators in California*. Environmental Defense, New York, N.Y.

Samuelson, S., D. Dabdub, and J. Brouwer. 2005. *Air Quality Impacts of Distributed Generation.* University of California, Irvine California Energy Commission. 500-2005-069. www.energy.ca.gov/pier/environmental/reports.html#outdoorairquality.

The Energy Foundation (TEF). 2002. *Performance and Cost Trajectories of Clean Distributed Generation Technologies.* Prepared by the Energy Nexus Group.

Thimsen, David. 2006. *Xonon® Low-NOx Catalytic Combustion in Practice: Case Study of a 1,400 kW Combustion Turbine.* EPRI and the California Energy Commission's Public Interest Energy Research Program. CEC-500-2006-054.

TRW Systems. 2002. *Summary of Short-Range Dispersion Modeling Workshop Cosponsored by the California Energy Commission and the California Air Resources Board*. TRW Systems, Falls Church, Virginia. www.energy.ca.gov/pier/energy/2002-01-24-25_WORKSHOP_SUMM.PDF.

U.S. Department of Energy (U.S. DOE). 2000. *Strategic Plan for Distributed Energy Resources*. Office of Energy Efficiency and Renewable Energy and Office of Fossil Energy. U.S. DOE. Washington, D.C.

U.S. Department of Energy (U.S. DOE). 2002. *The Impact of Air Quality Regulations on Distributed Generation*. National Renewable Energy Laboratory. NREL/SR-200-31772. Golden, Colorado.

Appendix A

Current Status of Programs

Appendix A
Current Status of Programs

This section outlines those efforts that most closely address the air quality impacts of the existing and expanded use of DG in California.

Current Status: California

California Energy Commission: PIER Environmental Area

A. Ongoing PIER-EA Projects

1. In 2004, the PIER-EA began collaborating with the National Renewable Energy Laboratory to develop lifecycle information that could be used to better understand and quantify the environmental and health impacts of DG compared to those from existing central power plants and to identify how to reduce impacts that are determined to occur from the use of DG technologies. Thus far, the project has determined that the lifecycle emissions from the operation of natural gas-fueled DG are significant due to leaks from the production and pipeline delivery system. (Contract #500-02-004, MAQ-04-05)
2. The PIER-EA program currently has a project with the University of California, Riverside, to improve the meteorological input estimation in urban areas for incorporation to typical dispersion models. The project will measure microscale meteorological parameters in urban areas and use these to improve methods for estimating the flow and turbulence in the urban canopy and boundary layers from routinely available meteorological measurements. The result will be a model that combines the meteorological processor resulting from this effort with the modified AERMOD in the previous study to create a version of AERMOD suitable for urban applications. This project will improve the accuracy of dispersion models to predict the near source environmental impacts of DG operation in urban areas. The project is expected to be completed in fall 2008. (Contract #500-02-004, MAQ-04-06)
3. The project will also build upon the project by University of California at Irvine (UCI) that developed DG penetration scenarios for the South Coast Air Basin (SoCAB) for 2010 and estimated air quality impacts. Deployment scenarios will be developed for two future years and three emerging markets for the SoCAB. Distributed generation scenarios will be developed to represent various emissions portfolios that would characterize DG deployment in the California Central Valley (an area with very different industry, population, geography, and meteorology than the SoCAB) and estimate the potential impacts of different DG deployment scenarios on ambient air quality. The project is expected to be completed in summer 2008. (Contract # 500-02-004, MAQ-04-05)
4. PIER-EA is collaborating with ARB to research, develop, and demonstrate portable, relatively inexpensive, real-time ambient and indoor air monitors. These monitors will help researchers better determine the air quality impacts of DG equipment on specific

sites, which will support the appropriate siting and regulation of these units. (Contract # 500-01-031)

5. PIER-EA is currently funding a project conducted by University of California at Irvine (UCI) that is measuring the actual heat and electricity use minute-by minute in a variety of high-potential commercial and industrial applications, for the duration of an entire year. Approximately half of the facilities already utilize DG/CHP, and the real-world efficiencies of these applications will be determined. Facilities with no existing CHP system, but within industries that have shown high potential for using such a system, will also be measured to determine what the actual viability and efficiency of such a system would be. Finally, the project will provide information on the most efficient systems, facility types, as well as analyze the potential air quality impact of introducing these systems. The project is expected to be completed in summer 2009. (Contract # 500-02-004, MAQ-07-01)

B. *Completed PIER-EA Projects*

1. PIER-EA completed its project with the College of Engineering - Center for Environmental Research and Technology (CE-CERT) at the University of California, Riverside, to study the problem associated with the measurement of very low (less than 5 parts per million by volume [ppmv]) NO_X concentrations. It was thought that existing methods might have uncertainty levels the same order of magnitude as the measurements; however, results indicated that this is not the case. The study found that the NO_X emissions of any commercial system can be measured to ~2 ppm. However, the methods used for the NO_X work were unable to account for the ammonia used in the simulated exhaust when there was also CO_2 present in the simulated exhaust, and that discrepancy will need to be examined further. The U.S. Environmental Protection Agency, ARB, the South Coast Air Quality Management District, and the San Diego Air Pollution Control District participated on the technical advisory committee. (Interagency Agreement No. 700-99-019).

2. In 2000, the PIER-EA program conducted a project with the University of California, Irvine, that successfully demonstrated a comprehensive active control strategy for reducing NO_X formation in industrial gas burners and stationary gas turbines. The project evaluated sensors that could provide feedback to adjust combustion variables and control NO_X formation. Researchers found that it was possible to use a pressure transducer near the burner to measure pressure waves from pollutants that might enable systems to adjust the burner to create less of that pollutant. It also found that it is possible to measure color changes in the flame that would indicate more or less production of a pollutant, which could also be used to adjust the burner accordingly. The strategy is still pre-commercial, but it could be used eventually to prevent NO_X formation in DG units. The project was coordinated with Southern California Gas, the Maxon Corporation, the COEN Corporation, and the California Air Pollution Control Officers Association (CAPCOA). The

combustion lab at UC Irvine plans to test this combustion strategy further; however, more development needs to be conducted before it can be commercialized. (See the Energy Commission report, *Active Control for Reducing the Formation of Nitrogen Oxides in Industrial Gas Burners and Stationary Gas Turbines* (publication 600-00-009) at www.energy.ca.gov/pier/final_project_reports/600-00-009.html. (Contract 500-97-013, Project 9)

3. In 2001 the PIER-EA program completed a project with Electric Power Research Institute (EPRI) to establish an acceptable emission certification protocol for distributed generators, particularly small combustion turbines, fuel cells, and internal combustion engines. It included a scoping study on how to select a third-party test facility to ensure credible, repeatable results that will facilitate responsible DG implementation. The purpose of the project was to reduce the cost and time for distributed generation technologies to meet future emissions regulations (EPRI TC Target 63). (Contract # 100-98-001)
4. In 2001 the PIER-EA program completed a project with Arthur D. Little to assemble an inventory database containing detailed information on the number, size, type, location, fuel used, age, and emission characteristics of installed back-up generators (BUGs) ≥ 300 kW in California. The project also assessed means to mitigate the air emissions associated with increased BUG operation, including evaluation of alternative fuels that could be used to lower emissions in these units and a survey of emissions control hardware that could be used on BUGs. (Contract No. 500-98-013, part of Work Authorization 20-AB-00). The report, *Emission Reduction Technology Assessment for Diesel Backup Generators in California,* can be found at www.energy.ca.gov/reports/2002-02-15_500-01-028.PDF.

5. In 2003 the PIER-EA program, with joint funding from the Energy Foundation, completed a project with the University of California, Riverside, to understand the Energy, Economics, Environment and Education of Distributed Generation Policy (Contract 500-99-013). The report, *The Four Es of DG Policy in California: Energy, Environment, Economics, and Education* (P500-03-100), outlines the policy options that could improve the use and application of environmentally friendly DG in California. The report can be accessed at www.energy.ca.gov/pier/final_project_reports/500-03-100.html.

6. In 2005 the PIER-EA program completed a project with the College of Engineering - Center for Environmental Research and Technology (CE-CERT) at the University of California, Riverside, to develop a methodology to assess and quantify the air quality impacts of Backup Generators (BUGs) and verify that methodology on the BUGs operating in California. This project estimated the air quality impacts of rolling blackouts in 2001 and identified particulate matter (PM) reductions from use of emissions controls. It focused primarily on BUGs, but the methodologies developed are applicable for analyses of more general distributed generation technologies when and where appropriate. Two project reports describe the work:

- *Air Quality Implications of Backup Generators in California - Volume One: Generation Scenarios, Emissions and Atmospheric Modeling, and Health Risk Analysis.*
- *Air Quality Implications of Backup Generators in California - Volume Two: Emission Measurements from Controlled and Uncontrolled Backup Generators.*

They can be accessed at the California Energy Commission's website at www.energy.ca.gov/publications/displayOneReport.php?pubNum=CEC-500-2005-048 and www.energy.ca.gov/publications/displayOneReport.php?pubNum=CEC-500-2005-049. A project summary of the project can be found at www.energy.ca.gov/pier/environmental/project_fact_sheets/IA-500-00-033.html. (Contract 500-00-032)

7. In 2005 the PIER-EA completed a project with the Gas Technology Institute (GTI) to address the inadequacies of the existing PM source test methods. A compact dilution sampler was designed and tested in this project. Detailed operating procedures evolved during the course of the program as weaknesses and problems were identified. Procedures are generally adequate for research purposes. However, further development and testing is needed to improve dilution methods and develop more robust emission factors and speciation profiles. Dilution sampling in this project indicates $PM_{2.5}$ mass emissions from gas-fired sources are extremely low, probably near ambient air $PM_{2.5}$ concentrations in many cases. This indicates that existing methods may be overpredicting emissions from natural gas fuel combustion by a significant margin. Although this effort did not test DG units, the test method is applicable to DG technologies. For more information about this project, see the California Energy Commission's website at www.energy.ca.gov/pier/environmental/project_fact_sheets/700-00-002.html. Multiple final reports on the project can also be found at www.energy.ca.gov/pier/final_project_reports/CEC-500-2005-032_to_44.html under reports CEC-500-2005-037 through CEC-500-2005-044 (Contract No. 700-00-002).

8. In 2006 the PIER-EA program completed a project with the University of California, Irvine, to determine the regional and overall environmental impacts of widespread DG implementation in southern California. Researchers developed and analyzed several DG implementation strategies that represent both realistic market penetration and bounding case studies for the year 2010 and evaluated the associated air quality impacts of using these technologies. Results of the study show that realistic DG implementation scenarios in 2010 increase basinwide emissions less than 0.5%. These scenarios can increase levels of ozone by 3 parts per billion (ppb) in some areas in non-attainment and change $PM_{2.5}$ concentrations by $\pm$ 3 $\mu g/m^3$. However, the model used to predict these impacts were on a 5-kilometer grid scale and therefore cannot estimate near-field environmental impacts, which could be much higher. Results from the study show that the least environmental impacts occur when low emission DG technologies or DG equipped with CHP are used, which can effectively reduce emissions and in some cases lower emissions from current levels when boilers are replaced. Factors that increase

emissions and air pollutants include: using higher emission DG technologies, locating many DG in the same region, and using DG for peak (as opposed to continuously loaded) operation. For the final report and appendices, please visit the California Energy Commission's website at www.energy.ca.gov/pier/final_project_reports/CEC-500-2005-069.html . For a project summary, please visit the California Energy Commission's website at www.energy.ca.gov/pier/environmental/project_fact_sheets/500-00-033.html. (Contract 500-00-033)

9. In 2006 PIER-EA completed a project with the University of California at Riverside and ARB on a project to improve air dispersion modeling so that elevated and ground-level urban power plant emissions can be modeled more accurately over short distances to support environmental justice evaluations and to account for the increased use of DG technologies in California. This work builds upon work by the ARB and others to develop an algorithm to incorporate into AERMOD (a commonly used dispersion model) to improve the accuracy of estimating the impact of near ground-level urban emissions sources at distances of tens of meters to a few kilometers from the source. The results provide data to indicate that sources near shorelines can have different dispersion characteristics and may help diffuse impacts of elevated sources (i.e., power plants) and increase impacts from ground-level sources (i.e., DG) due to the low, pervasive boundary layer. The project also provided a model evaluation database from tracer experiments that have been conducted in several urban areas. The final report for this project is *Improvement of Short Range Dispersion Models to Estimate Air Quality Impact of Power Plants in Urban Environments* (CEC-500-2007-096). (Contract #500-01-038)

Other PIER areas are working on DG equipment development, performance evaluations, interconnection issues, test and evaluation protocols, and more. The itemized list below outlines some of the efforts most applicable to the environmental aspects of DG development and implementation. One plan that applies to all areas of the California Energy Commission is the *Distributed Generation Strategic Plan,* which formalized the policy, vision, mission, and goals of all Energy Commission Distributed Energy Resource Activities. This report can be found at www.energy.ca.gov/publications/displayOneReport.php?pubNum=P700-02-002.

California Energy Commission: PIER Environmentally Preferred Advanced Generation (EPAG) Area

A. Ongoing EPAG Projects

1. The Environmentally Preferred Advanced Generation (EPAG) area of the PIER program facilitates the widespread use of non-renewable DG equipment, with a focus of improving California's air quality by developing reliable, inexpensive, emission-reduction technologies for reciprocating engines, small turbines and microturbines, fuel cells, and hybrid fuel cell/microturbine technologies. Near-term efforts focus on reducing reciprocating engine emissions and standardizing interconnection requirements. Mid-term work will target DG emission and cost reductions, while improving the performance characteristics of small turbine and microturbine generators.

In the long term, EPAG plans to develop cost-competitive, highly efficient, innovative technologies such as fuel cells and hybrids, which are exceptionally clean and can be used in CHP applications.

2. The EPAG area is technical lead for a collaborative, multi-state project that is developing nationally accepted performance testing protocols for DG systems. Researchers will develop testing procedures, verify the procedures through application to DG systems, and compile testing results into an Internet-accessible database. The project is coordinated through the Association of State Energy Research and Technology Transfer Institutions (ASERTTI), the New York State Energy Research and Development Authority (NYSERDA), and the Illinois Department of Commerce and Commercial Affairs. Currently, field, laboratory, and durability protocols have been developed for criteria pollutants from microturbines, small turbines, fuel cells, and reciprocating engines. Protocols for assessing case studies have also been developed, and those are available in draft form at www.dgdata.org.

3. The EPAG area is also working with Alzeta Corporation and Solar Turbines, Inc. to continue research on developing an ultra-low NO_X combustor that can be retrofit on a range of sizes of gas turbines. This work is focusing on high-temperature and high-pressure conditions typical in combustion turbines and will result in very low cost NO_X controls that will not require exhaust clean-up systems.

4. The EPAG area formed an Advanced Reciprocating Internal Combustion Engines (ARICE) collaborative that focuses on reducing DG emissions. The collaborative facilitates R&D, demonstration, and commercialization of ARICE technologies and coordinates policy efforts with utilities, ARB, and other agencies to help advance the use of inexpensive, reliable, efficient, and clean DG technologies. Currently, this work is focusing on the development of a homogenous charge compression ignition (HCCI) and on-board natural gas reforming to improve engine efficiency, reduce NO_X emissions, reduce costs, and improve reliability. For more information, see www.energy.ca.gov/pier/arice/.

5. EPAG is working with U.S. DOE to evaluate the feasibility and facilitate the implementation of advanced CHP technologies at federal sites. This project is developing CHP applications at three federal sites in California. Each site will have its own characteristics and use a different DG technology. Researchers will test the DG performance evaluation protocols developed at the Energy Commission at these sites.

6. The EPAG team is working on a project with Waukesha Engine and Dresser, Inc. to develop and demonstrate a natural-gas-fueled reciprocating engine system with emissions reduction technology and fuel reformation. A goal of the project is to decrease engine emissions by 90%. By 2005, project participants expect to lower NO_X and CO by combining exhaust gas recirculation (EGR) with fuel enhancement, and a three-way catalyst will further reduce those emissions.

B. Completed EPAG Projects

1. EPAG funded Catalytica to complete development of the Xonon® Cool Combustion system—a catalytic combustor for use on small gas turbines—that eliminates the need for exhaust gas cleanup. Kawasaki gas turbines operating with this technology now produce less than 3 parts per million (ppm) NO_X emissions, which is a 90% reduction over past performance. Results from the EPAG demonstrations of the Xonon Cool Combustion system are available in two PIER final reports, at www.energy.ca.gov/pier/final_project_reports/CEC-500-2006-054.html and www.energy.ca.gov/pier/final_project_reports/CEC-500-2005-174.html.

2. Together with Alzeta Corporation, EPAG developed and tested a gas turbine semi-radiant burner (GTSB). Both NO_X and CO were measured under 1 ppm at times during testing. A report on the results of this work is available at www.energy.ca.gov/pier/final_project_reports/600-01-002.html.

3. EPAG also worked with the Gas Technology Institute and BKM (CAP), Inc., to develop a MicroPilot® diesel-cycle natural gas engine.

4. EPAG completed a project with Arthur D. Little to identify and screen candidate NOx and PM emission control options for near term application to mitigate the impacts of diesel BUG use. The report, *Emission Reduction Technology Assessment for Diesel Backup Generators in California,* can be found at www.energy.ca.gov/publications/displayOneReport.php?pubNum=P500-01-028.

California Energy Commission: PIER Energy Systems Integration (ESI) Area

A. Ongoing ESI Projects

1. The Distributed Energy Resources Integration (DERI) program within ESI focuses on issues related to the use of relatively small-scale energy resources as part of the larger interconnected electricity grid. Issues addressed by this area include interconnection standards and technology, impacts of distributed energy resources on the electricity grid, and market integration of distributed energy resources.

2. The DERI program is focusing on analyses to support the development of market mechanisms to capture DG benefits and conducted several projects in 2003 to address this issue. This work will provide data to policy and decision makers and will help incorporate the environmental contributions of DG technologies into policies and regulations.

B. Completed ESI Projects

1. The PIER Energy Systems Integration area and EPRI developed the Energy Commission's Distributed Energy Resources (DER) website. This site contains information usable by policy makers, consumers, and researchers who wish to evaluate and install distributed resources. See www.energy.ca.gov/distgen.

2. The ESI area developed the *PIER Strategic Program—Strategic Distributed Energy Resources Research Assessment* (CEC 2001a) to assess DG interconnection, grid effects, and market integration issues. This study identified the status of those issues and gave researchers a baseline from which to focus future research. It also recently published *Identifying Distributed Energy Resources Research Priorities Through Emerging Value Networks* (CEC 2003b; CEC 2005), which should help researchers better identify the potential use of various DG technologies. The 2003 version of the report can be found at www.energy.ca.gov/pier/esi/documents/2003-04-10_PIER_ESIR.PDF, and the revised 2005 version can be found at www.energy.ca.gov/pier/final_project_reports/CEC-500-2005-207.html.

California Air Resources Board (ARB)

1. The ARB conducted a project with Dr. Akula Venkatram at UC Riverside to develop a dispersion algorithm for source-receptor distances of less than 50 meters. Whereas the traditional Gaussian plume models are based on field studies where receptors were placed from 50 m to 1 kilometer from the source, this study includes field tracer experiments to validate model predictions in the near field. By comparing model estimates with measured tracer gas concentrations at different neighborhood areas and different meteorology, ARB will be able to determine which models are the most reliable. Field studies were conducted at Barrio Logan, near San Diego, and the Energy Commission is co-sponsoring current field studies at Wilmington, in Los Angeles county. The data from these studies is being used for model development.

2. The ARB established a Diesel Risk Reduction Program to address diesel emissions from all sources and has tested emissions from certain categories of diesel engines. A Diesel Advisory Committee, composed of a broad base of stakeholders, was formed to help develop a risk management guidance document and a risk reduction plan. It published those documents—*Risk Reduction Plan to Reduce Particulate Matter Emissions from Diesel-Fueled Engines and Vehicles* (ARB 2000a), and *Risk Management Guidance for the Permitting of New Stationary Diesel-Fueled Engines* (ARB 2000b) in 2000. ARB is building on that work by designing specific statewide regulations designed to further reduce diesel PM emissions from diesel-fueled engines and vehicles. These air toxic control measures (ATCMs) will apply to two classes of engines : (1) new and in-use stationary combustion ignition (CI) engines > 50 horsepower (hp), and (2) stationary CI engines ≤ 50 hp. To help inform this process, ARB is currently surveying owners of stationary emergency/stand-by diesel-fueled engines in California, to get information about the engine's make, model, age, and actual hours of operation for the past three years. This work will encompass a broader range of DG equipment sizes than those surveyed by the Energy Commission in its BUGs inventory. For more information, see www.arb.ca.gov/diesel/dieselrrp.htm.

3. The ARB's Toxic Air Contaminant program conducted a technical evaluation of some commercial technologies for diesel engine emissions reduction. Criteria include availability, emission reduction efficiency, costs, adverse impacts, and other relevant factors.

4. In 2003 ARB developed its *Strategic Plan for Research*—a roadmap of its research priorities for 2001 through 2010. The plan indicates that ARB's research in this area will focus on advancing the development and commercialization of the cleanest, most efficient DG generation technologies and better characterizing the potential human exposure and health impacts associated with increased DG use.

5. The ARB and Distributed Utility Associates calculated the net air emissions effects from the potential use of DG technologies likely to be added in California in the next decade. The study included microturbines, Advanced Turbine Systems (ATS), combustion turbines, diesel engines, dual-fuel engines, Otto/spark engines, phosphoric acid fuel cells, and proton exchange membrane (PEM) fuel cells. The resulting report, *Air Pollution Emission Impacts Associated with Economic Market Potential of Distributed Generation in California* (Iannucci et al. 2000), stated that, using emissions rates for individual DG technologies and average emissions of grid-connected units, it was possible to estimate net increases or decreases in statewide emissions from the use of DG technologies. It also concluded that the increased use of DG in California would increase net emissions in the state in the near term.

6. The ARB's *Guidance for the Permitting of Electrical Generation Technologies* (ARB 2002) summarizes existing regulations and outlines best available control technologies for a number of different DG technologies. For more information, see www.arb.ca.gov/energy/dg/documents/guidelines.pdf.

7. The ARB has also identified and verified PM and NOx control devices for various diesel engines used in California. They list these devices, along with their level of reduction, at www.arb.ca.gov/diesel/verdev/verdev.htm.

The website for the ARB's DG projects is www.arb.ca.gov/energy/dg/dg.htm.

South Coast Air Quality Management District

1. The SCAQMD has done emissions testing and research on the emissions levels of in-use natural gas-fired DG in Southern California, and found that their levels greatly exceed certification levels. They are proposing regulations to reduce the emissions levels of natural gas and biofuels and to require continuous emissions measurement systems or air-to-fuel ratio controllers on DG units. www.aqmd.gov/rules/proposed.html#11102.

Current Status: Regional and National

Center for Clean Air Policy (CCAP)

1. The Center for Clean Air Policy is a small nongovernmental organization that focuses on developing solutions to local and global air pollution. The center conducted a study that modeled air emissions from medium-sized CHP district energy systems. They also developed and ran an electricity dispatch model that models the air emissions impacts of increasing DG penetration. This Distributed Resource Net Emissions Model (DR NEMO)

models new DG capacity based on a technology diffusion model derived from the National Energy Modeling System (NEMS) and implemented in the Natural Resources Defense Council Distributed Resources Emissions Model (DREM). That work examined the penetration of DG technologies, along with their environmental and economic impacts, and their impact on new central station capacity. CCAP's New England-focused run of DR NEMO concluded that CO_2 and SO_2 changed little, but that NO_X emissions could increase significantly with a high penetration of DG units. CCAP is pursuing funding to model other regions.

Electric Power Research Institute (EPRI)

1. EPRI has developed a roadmap of Distributed Generation that explores a number of ways in which DG may emerge in the future. The analysis considers that end-users employing DG will do so to achieve energy cost savings and higher reliability. The analysis considers penetrations that would benefit both the energy supply and transmission system, and it investigates six scenarios through 2015. The report is *Distributed Energy Resources: Current Landscape and a Roadmap for the Future* (report number 1008415), published in December of 2004, and it can be found at www.epri.com.
2. EPRI has collected and summarized available data on the emissions of internal combustion engines, small gas turbines, microturbines, and fuel cells that existed as of December 2003. The range of fuels include diesel, gas, and biofuels, and the pollutants include criteria, global warming, and hazardous air contaminants. The report also outlines the existing data gaps in understanding the emissions from these DG units. The report concludes that there is a lack of consistent publicly available information on criteria emissions from currently existing and emerging DG units, very little for PM, and none for $PM_{2.5}$. The report, *Distributed Energy Resources Emissions Survey and Technology Characterization,* can be found at www.epri.com.
3. EPRI is gathering emissions data from microturbines, Stirling engines, and reciprocal engines.
4. Through its Electricity Innovation Institute, EPRI is conducting research to study the environmental impacts of DG deployment, with a focus on developing solutions while the technologies are still pre-commercial. This effort is characterizing air emission levels of criteria pollutants, air toxics, and greenhouse gases from key DG technologies.
5. EPRI developed SOAPP CT2.5 software, which generates project-specific conceptual designs, including heat balances, cost estimates, and financial analyses of distributed generation power and cogeneration plants, using small gas turbines (500 kW–28 MW). See www.soapp.com/soapp/default.htm.

The Energy Foundation

1. The Energy Foundation is a partnership of major foundations interested in sustainable energy. Their report—*Can We Have Our Cake and Eat It, Too? Creating Distributed Generation Technology to Improve Air Quality*—examined DG emissions levels and recommended a framework for DG emissions regulations. This report can be downloaded at www.raponline.org/ProjDocs/DREmsRul/Collfile/Lents-Allison.pdf.
2. An Energy Foundation study projected cost and performance information for DG/CHP technologies with emission controls over the next decade using ARB's DG emission certification regulations for 2003 and 2007 as benchmarks (TEF 2002).

Lawrence Berkeley National Laboratory (LBNL)

1. Lawrence Berkeley National Laboratory has developed a Distributed Energy Resources Customer Adoption Model (DER-CAM) that will help users estimate and incorporate the penetration of distributed generation technologies into PIER's proposed modeling scenarios. In one project, LBNL used DER-CAM to model a hypothetical DG adoption scenario for a San Diego strip mall. Another LBNL project combined DER-CAM analysis with a geographic information system (GIS) analysis of local land use constraints that would inhibit the use of DG, to better identify DG adoption patterns (Edwards 2002). The report is available at www-library.lbl.gov/docs/LBNL/501/32/PDF/LBNL-50132.pdf.

U.S. Department of Energy (U.S. DOE)

1. The U.S. Department of Energy's DG-focused work resides in a variety of different Offices, programs, and initiatives, including the Distributed Power Program and the Buildings, Cooling, Heating, and Power (BCHP) initiative, which works to better integrate power generation systems with building thermal systems to facilitate more efficient energy use. The U.S. DOE's Distributed Energy Program can be found at www.eere.energy.gov/de/. Various aspects of DG work are also being conducted at the National Renewable Energy Laboratory, which can be found at www.nrel.gov/programs/deer.html, in the Office of Fossil Energy, and in many other areas. The Oak Ridge National Laboratory recently completed a survey of all the software to determine the economics and efficiencies of DG and CHP systems, which is available at www.ornl.gov/sci/femp/pdfs/0302-chp_software_survey.pdf.
2. In 2000 U.S. DOE published its *Strategic Plan for Distributed Energy Resources* (U.S. DOE 2000), which outlines the agency's mission in this area through 2005, but it did not identify any specific projects being undertaken to assess DG and air quality. The report is available at www.eere.energy.gov/de/program_plan.html. More recently, U.S. DOE/NREL issued a report on the impact of air quality regulations on DG implementation. A link to this report and many other reports on DER project, roadmaps, and market analysis is available at www.eere.energy.gov/de/publications.html#general.

3. In 2000 U.S. DOE and other government agencies conducted urban tracer studies in and around Salt Lake City, Utah, to determine emissions dispersion under U.S. DOE's Chemical and Biological National Security Program. This URBAN 2000 study resulted in datasets that resolve interacting scales of motion from the level of individual buildings (tens of meters) to the region (tens of kilometers through 100 kilometers)—all under the same meteorological conditions. It can be found at www.osti.gov/energycitations/product.biblio.jsp?osti_id=15020777. Whereas URBAN 2000 studied an urban nocturnal boundary layer (i.e., stable to neutral conditions), a follow-on study in 2003 examined an urban daytime boundary layer (i.e., neutral to unstable conditions) http://ju2003.pnl.gov/study.html. Dispersion model researchers will be able to use these data to evaluate dispersion model performance over a broad range of atmospheric conditions.
4. A Distributed Generation Analysis Tool (version 1.0) was developed recently by the Science Applications International Corporation (SAIC), with assistance from the National Association of State Energy Officials (NASEO) and support from U.S. DOE. This software enables users to conduct a 20-year life-cycle cost analysis and assess the environmental impacts of DG technologies. Users input data and the analysis tool generates emissions and operating summaries, as well as financial analyses. It focuses on engines, turbines, microturbines, and fuel cells, and provides air emissions factors in pounds per kilowatthours (lb/kWh) www.naseo.org/energy_sectors/power/distributed/default.htm.
5. The U.S. DOE runs the Advanced Reciprocating Engine Systems (ARES) program. This national effort seeks to design, develop, test and demonstrate cleaner, more reliable, and more efficient reciprocating engine systems for DG applications. For example, the program's goal for NO_x emissions would reduce them by about 95% when compared with current technologies.
6. The U.S. DOE's Energy Information Administration provides statistics and data on the use of various forms of electricity and fuel use in the United States. This site can be accessed at www.eia.doe.gov/.

The website for U.S. DOE's distributed generation projects is www.eere.energy.gov/de/.

U.S. Environmental Protection Agency (U.S. EPA)

1. The U.S. EPA developed eGRID (Emissions and Generation Resource Integrated Database), which is a comprehensive database of the environmental characteristics of most electric power generation in the United States. Based on 24 federal (U.S. EPA, Energy Information Administration, and Federal Energy Regulatory Commission) data sources of power plants and power generating companies, this resource integrates emissions and generation data that users can draw from to develop emissions inventories and emissions standards, estimate avoided emissions, and examine the NO_X, SO_2, CO_2, and mercury emissions of generating units in the United States. Now in version 2.01, eGRID is available in a Data

Browser or spreadsheet format. In April 2007 eGRID2006 version 2.1 was released. It can be accessed at www.epa.gov/cleanenergy/egrid/index.htm.